The GEOCON Manual:

Documentation for NGS programs

GEOCON, version 1.1
and
GEOCON11, version 1.1

March 13, 2014

This document replaces the following earlier documents:

1) GEOCON v1.0 Operating Instructions (July 6, 2012)
2) GEOCON v1.0 User Guide (July 6, 2012)

This document contains two primary parts:

I. **Operating Instructions** – Outlining the basic functionality of GEOCON (v1.1) and GEOCON11 (v1.1)

II. **Technical Information** – Containing information about the data behind GEOCON (v1.1) and GEOCON11 (v1.1) and the creation of those two programs

For additional technical details, readers are directed to the GEOCON v1.0 technical report by Dr. Dennis Milbert, here:

http://beta.ngs.noaa.gov/GEOCON/techreport.pdf

Readers are cautioned that the above report was for version 1.0 only and information in it may have been superseded by later versions of GEOCON.

I. Operating Instructions

1. Introduction

GEOCON performs three-dimensional coordinate transformations between NAD 83 ("HARN"[1]) coordinates and NAD 83(NSRS2007) coordinates. **GEOCON11** performs three-dimensional coordinate transformations between NAD 83 (NSRS2007) coordinates and NAD 83(2011) coordinates.

Both programs work exclusively in geodetic latitude, geodetic longitude and ellipsoid height only. Both programs also issue information about the quality ("worst case estimates") of the transformation at each point, as well as notifications ("warnings") when transformations are occurring in particularly questionable areas of confidence.

GEOCON and GEOCON11 function in very similar ways. To save space, this documentation will address just GEOCON. Users may presume that such documentation applies equally to GEOCON11 unless explicitly stated otherwise, in which case the text will be red and the specifics of GEOCON11 given.

GEOCON requires, as input from the user, a file of three dimensional coordinates in one of two allowable formats. Either as pairs of "FGCS Blue Book" standard *80* and *86* records (one pair per point), or in a ***Free Format*** style, one record per point. *For purposes of succinctness, a file of paired *80* and *86* records will be simply called "**Blue Book Format**", despite not containing any other Blue Book records than the *80* and *86* pairs.*

The coordinate transformation and the associated quality indicators are obtained through biquadratic interpolation within a series of grids. Notifications are issued based on text formatted "info" files. Third party applications may obtain identical results if they use the same grids, info files and algorithms. Three files will be output – (1) transformed coordinates and quality indicators, (2) notifications and (3) clipped points. The first file can be either Blue Book Format or Free Format style. The second file is in a fixed narrative-style format and the third (clip) file will match the format of the *input* file.

GEOCON employs high-resolution grids (1' by 1') to obtain unprecedented fidelity in modeling coordinate differences. Frequently, one may see that the reported quality is extremely small (e.g. 1 cm or better), and might mistakenly be considered comparable to a geodetic readjustment of survey measurements. Nonetheless, the National Geodetic Survey considers actual readjustment of survey measurements, and not coordinate transformations, as "best practice".

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[1] "HARN" is in quotes because GEOCON v1.0 and v1.1 were built without distinguishing between HARN, FBN or mixes of the two. GEOCON v1.0 and 1.1 grids were built from two coordinate sets on individual points: The first coordinate set was the NAD 83(NSRS2007) coordinate set for a point. The second coordinate set was the most recent published NAD 83 coordinate set that was after NAD 83(1986) and before NAD 83(NSRS2007), without consideration of whether that coordinate set was from a HARN, an FBN, a mix of both, or neither. Thus the quotes indicate it is not explicitly just the HARN realization. While this choice satisfies many users, NGS is aware that users of the NSRS in some states and territories explicitly distinguish between the HARN and FBN realizations of NAD 83 in their state or territory. A new version of GEOCON which explicitly addresses this issue is being developed as of 2014.

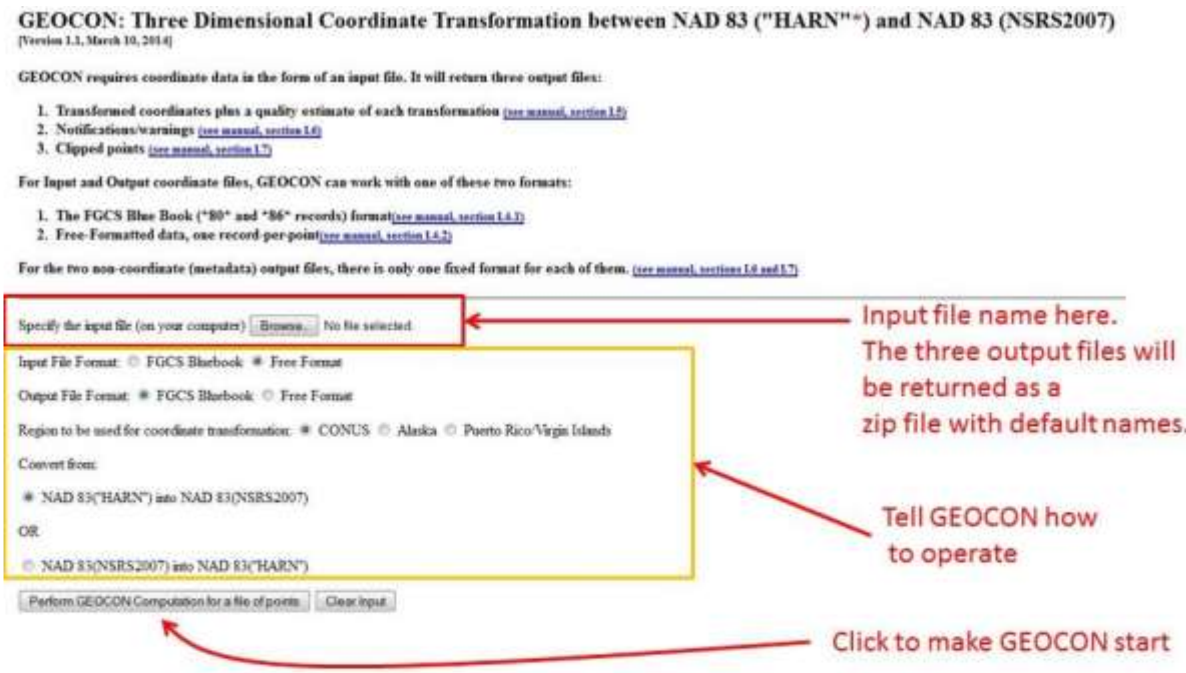
2. Running GEOCON

GEOCON can be run in one of two ways. Either the program can be run in "command line" mode or through the Web interface. In both cases, the prompts are the same and the actual processing engine and results are identical.

2.1. Example GEOCON Session – Command Line Mode

```
C:/>geocon.v1.1

Program GEOCON, v1.1, Jan 30, 2014
----------------------------------

This program will take as input the following formats:
     1 = FGCS Bluebook Formatted pairs of 80/86 records
     2 = A free-formatted list of lat, lon, h and info
        Which type are you inputting?  : 2

This program will give as output 3 different
files.  The first (primary) file will be your transformed
coordinates *and* a quality indicator for each
transformation performed.  The format of that file can
be Blue Book or Free Format.  The second file will
contain notifications (see manual) in a fixed format.
The third file will contain any of your input points
which do not fall within the region in which you tell
GEOCON to work.  The format of this clipped-point file
will be the same as your input file.

For the primary output file, your choices are:
     1 = FGCS Bluebook Formatted pairs of 80/86 records
     2 = A free-formatted list of lat, lon, h and name
        Which type of output do you want? : 2

Free formatted input file name            : myfile.in
Free formatted output file name           : myfile.out
Clipped points file name                  : myfile.clp
Notification/warning file name            : myfile.not

Transformations will take place in one of the
following regions.  Points in your input file which
do not fall into your region of choice will be put
into the "clip" file.

     Region number 1 -- CONUS (N24/50, E235/294)
     Region number 2 -- Alaska(N46/77, E166/232)
     Region number 3 -- Puerto Rico/Virgin Islands (N17/20, E292/298)
     -----------------------------------------------------------------
In which region do you wish to transform points? : 1

You may convert either:
1 -  From NAD 83("HARN") to NAD 83(NSRS2007) or
2 -  From NAD 83(NSRS2007) to NAD 83("HARN")

Which conversion do you wish to perform? : 1

You have chosen to convert from NAD 83("HARN") to NAD 83(NSRS2007)
-----------------------------------------------------------------
 Transformation grids successfully loaded

Program complete....
Number of points successfully transformed     :       29
Number of points that were outside the region :        0
Number of notifications issued                :        2

Press ENTER key to stop program...
```

2.2. Example GEOCON Session – Web Interface



3. Operation

Operation of GEOCON through the web interface is fairly straightforward; as such, the below instructions only address running GEOCON in command line mode. Although the example of a Windows operating system is used, these instructions can easily be generalized to any interface with a command line operation.

Assume that **`geocon.exe`** and its supporting grid and info files (see section 8) have been placed in a folder (or subdirectory) named “MyDir” on a PC with a Windows operating system. Open the “MyDir” folder. Copy or move an input file containing the coordinates of points to be transformed into the “MyDir” folder. Assume, for the sake of this example, that the input file is named “myfile.in”. Simply double left click on the “**`geocon`**” file in “MyDir” (full file name is “**`geocon.exe`**”). This will create a command prompt console window, and will automatically start GEOCON in the console window.

GEOCON will first ask for the formats of the input and output files. It will then ask for a series of file names. The first file name is the input file containing coordinates to be transformed. The remaining file names are output files that will be created by GEOCON. On output, GEOCON will overwrite a file if you reuse a file name and it is not write-protected. File names use standard Windows OS conventions, but are limited to 88 characters. File name extensions (e.g. “**`myfile.out`**”) are supported if the user provides them.

After prompting for the file names, GEOCON will prompt for the region to be used for the coordinate transformation. The regions[2] are:

```
1     CONUS                          24-50 N,    66-125 W  (235-294 E)
2     Alaska                         46-77 N,   128-194 W  (166-232 E)
3     Puerto Rico/Virgin Islands  17-20 N,     62-68 W  (292-298 E)
```

Enter the region number for the points in the "**`myfile.in`**" file. If they are in the conterminous U.S., enter a "1". Points in the selected region will be transformed and their transformed coordinates placed in the output file. Points outside the region will be written to the clip file, using the same format as the input file. If the wrong region is selected, then all of the input points will be clipped, and no points will be transformed or written into the output file.

The last prompt is for the direction of the coordinate transformation. The prompt is:

```
Which conversion do you wish to perform? :
```

If you wish to transform from NAD 83("HARN") into NAD 83(NSRS2007), then respond with a "1". If, on the other hand, you wish to transform from NAD 83(NSRS2007) into NAD 83("HARN"), then respond with a "2". GEOCON will then confirm the direction of the transformation in the subsequent line.

GEOCON will then issue a message indicating that it has successfully loaded the coordinate transformation grids. GEOCON will transform the points in the input file and write them into the output file. For each transformed point, an associated transformation quality indicator will be written into the output file as well[3]. If a point is clipped, due to falling outside the designated region boundaries, the untransformed point will be written into the clip file. Supplemental information regarding potential sources of poor quality results will be listed in the notification file if appropriate.

Finally, GEOCON will indicate its completion by issuing the prompt:

```
Press ENTER key to stop program:
```

When you press the enter key, GEOCON will stop, and the command prompt console window will close. The output files created by GEOCON are formatted ASCII text files, and may be inspected by any suitable application, such as Notepad.

Note it is also possible to manually launch a command prompt console window within Windows. If this is done, then use the "cd" command to maneuver to the "**`MyDir`**"

[2] There are no official NAD 83(NSRS2007) coordinates for Hawaii. However, a single control point, KOKEE, (PID = TT3487) was inadvertently published in the NGS database as NAD 83(NSRS2007). This position was subsequently removed from the NGS database in 2012. Hence, there are no GEOCON coordinate transformations for Hawaii.

[3] GEOCON v1.0 originally created a separate "quality" file. For version 1.1, the quality indicators are now put directly into the output file containing the transformed points and are associated with each transformed point. There is no longer a separate "quality" file.

subdirectory. One may then start GEOCON by typing "**geocon**" at the command prompt. If a console window is manually created, then it will not close when GEOCON stops.

4. The Input File

The user is responsible for providing an input file containing coordinates (latitude, longitude, ellipsoid height) for points to be transformed between NAD 83("HARN") and NAD 83(NSRS2007). For GEOCON11, the transformation is between NAD 83(NSRS2007) and NAD 83(2011). This file may be in one of two formats.

4.1 Blue Book Formatted Input

Under this option, the input file consists solely of *80* and *86* records as described in Chapter 2, Horizontal Observation (HZTL OBS) Data, of the Input Formats and Specifications of the National Geodetic Survey Data Base (the FGCS Blue Book), Volume I - Horizontal Control. Further detail may be found below in sections 9 and 10 "Format of Blue Book *80* Control Point Record" and "Format of Blue Book *86* Orthometric Height, Geoid Height, Ellipsoid Height"

If a user chooses this option, GEOCON requires the input file to consist solely of *80* and *86* records, entered pair wise. No other "Blue Book" records are allowed. That is, for each point to be transformed the users input file will have one *80* record (containing the latitude, longitude and designation) followed by an *86* record (containing the ellipsoid height.)

4.2 Free Formatted Input

Under this option, the file consists of lines ("records") of data, one record per point to be transformed. While called "Free Format", the allowable input file does have rules which must be followed. Those rules are:

1) Each point to be transformed must have 1 record of no more than 256 characters
2) Each record must contain at least three data fields: latitude, longitude and ellipsoid height, and the data fields must be in that order
3) Following the ellipsoid height, an optional "designation" data field may exist
4) Data fields (and sub-fields, see below) must be:
    a. Comma-delimited (1 comma plus extraneous spaces before or after the comma) or
    b. Space-delimited (1 or more spaces adjacent to one another).
5) Latitude and Longitude may be given in a variety of ways:
    a. With or without a hemisphere identifier (these are each one "sub field")
    b. Numerically there are three choices:
        i. Decimal Degrees (being 1 "sub field" each)
        ii. Integer Degrees plus Decimal Minutes (2 "sub fields" each)
        iii. Integer Degrees, Integer Minutes, Decimal Seconds (3 "sub fields" each)
6) If latitude has a hemisphere identifier, so must longitude and vice versa
7) Whatever numerical choice (Decimal Degrees, Deg/Min or Deg/Min/Sec) is used for latitude, the same must be used for longitude

8) If no hemisphere identifiers are given, latitudes will be interpreted in a positive North system (-90 ≤ lat ≤ +90) and longitudes will be interpreted in a positive East system (0 ≤ lon < 360).
9) Use of signs (+/-) are allowed but not required for latitude and longitude. If a sign is to be used in latitude or longitude it must:
   a. Precede only the degrees sub-field
   b. Abut the first numeral in the degrees sub-field
10) The designation (optional data field) will be taken as the first 30 characters following the first delimiter after the ellipsoid height
11) Each individual record may be differently formatted than the others, as long as any given record follows all of the above rules

Using the above rules, twelve different combinations (2 × 2 × 3) of possible input can be created under the umbrella of "Free Format":
1) Comma delimited vs. Space delimited [2 choices]
2) With Hemisphere Identifiers vs. Without Hemisphere Identifiers [2 choices]
3) Decimal Degrees vs Degrees+Minutes vs. Degrees+Minutes+Seconds [3 choices]

A table outlining these options and the twelve types of input they allow is below.

Type #	Comma or Space	Hemispere Identifiers?	Dec Deg or Deg/Min or Deg/Min/Sec	Example of one Record
1	C	Y	D	`N,43.958010919,W,88.543570436,205.770,3W97`
2	C	Y	DM	`N,43,57.4806552,W,88,32.6142262,205.770,3W97`
3	C	Y	DMS	`N,43,57,28.83931,W,88,32,36.85357,205.770,3W97`
4	C	N	D	`43.958010919,271.456429564,205.770,3W97`
5	C	N	DM	`43,57.4806552,272,32.6142262,205.770,3W97`
6	C	N	DMS	`43,57,28.83931,272,32,36.85357,205.770,3W97`
7	S	Y	D	`N 43.958010919 W 88.543570436 205.770 3W97`
8	S	Y	DM	`N 43 57.4806552 W 88 32.6142262 205.770 3W97`
9	S	Y	DMS	`N 43 57 28.83931 W 88 32 36.85357 205.770 3W97`
10	S	N	D	`43.958010919 271.456429564 205.770 3W97`
11	S	N	DM	`43 57.4806552 272 32.6142262 205.770 3W97`
12	S	N	DMS	`43 57 28.83931 272 32 36.85357 205.770 3W97`

Note that each of these twelve types can:
a) Be stretched into wider records by padding extraneous spaces around the delimiters
b) Have their "W" hemisphere identifiers replaced by "E" provided the longitude is changed to the right numerical value.

As such, type #1 could be both stretched and made E longitude (but still stay "type 1") as follows:

```
N ,  43.958010919  ,E,     271.456429564,       205.770     ,3W97
```

Similarly for all types in the above table. Note that the user does not need to know their "type number". The identification of types 1 through 12 in the table above is made internally by GEOCON and used to determine how the output file will be formatted (if the user requests a "Free Format" output file rather than a Blue Book output file).
As mentioned in rule #11, each record may be of any of the 12 types listed above. However, the output format will be a "cleaned" (no extraneous spaces, decimal points aligned in columns) version of whatever type is the very last record found in the input file.

A note on hemispheres and signs: If a latitude or longitude has both a hemisphere identifier *and* a sign, they will *both* be applied, quite possibly causing them to cancel one another! That is, if a user inputs for the latitude data sub-fields the following: "**N , -43.958010919**" this will be interpreted the same as "**S , 43.958010919**". In a similar way, "**W, -88.543570436**" will be interpreted as "**E, 88.543570436**". As such, it is strongly recommended that either hemisphere identifiers or signs be used, but not both unless the user is absolutely sure of the consequences. Particularly in the USA, users familiar with west longitudes should use "**W, 88.543570436**" or "**-88.543570436**". Failure to use either the negative sign or the W identifier (that is, using just "**88.543570436**") will cause the longitude to be interpreted in a positive East system as "**E, 88.543570436**".

4.3 Realizations of NAD 83 in the Input File

It is required that all the records in the input file be in the same realization of NAD 83, that realization being either NAD 83("HARN") or NAD 83(NSRS2007). It is absolutely critical that the response to the prompt

```
Which conversion do you wish to perform? :
```

is correct. If your input coordinates are NAD 83("HARN"), you must respond "1". If your input coordinates are NAD 83(NSRS2007), you must respond "2".

For GEOCON11, the required realizations in the input file are NAD 83(NSRS2007) and NAD 83(2011).

It is not required that all of the input records be in the same geographic region, though only one geographic region may be transformed at each running of GEOCON. However, it may be useful to organize data in that way. Any points in the input file that do not fall in the geographic region chosen by the user will be clipped, and written to the clip file using the same format as the input file.

5. The Output Coordinate and Quality File

GEOCON returns three output files to the user. The first file is the file containing transformed coordinates and quality indicators of those transformations. It is the only file of the three whose output format may be chosen by the user. Two output formats are allowed: Blue Book Format and Free Format.

5.1 Blue Book Formatted Output

If the user chooses Blue Book Format output, then this file consists of the transformed coordinates, placed into *80* and *86* records, and quality indicators[4] in *94* records[5]. (See section 5.3 for a description of the fields containing the quality information.) If the user provided a Blue Book formatted file as input, then all of the information in the *80* and *86* input records will be duplicated in the output file, except that the latitude,

[4] The "quality indicator" of the transformation is a conservative estimate of the possible errors in the transformation, based on worst-case outliers of points. See Part II, Section 5.

[5] While these records (*94*) appear to be Blue Book records, they are not part of the Blue Book.

longitude and ellipsoid height fields will be the newly transformed values. Specifically, GEOCON does not modify the designation in the *80* record, nor the orthometric height or the geoid height in the *86* record. Each paired set of *80* and *86* records will then be followed by one *94* record, containing the quality information about the transformation performed at that point.

If the user provided a Free Format input file, then the only non-blank information generated in the Blue Book formatted output file will be latitude (*80* record, columns 45-56), longitude (*80* record, columns 57-69), ellipsoid height (*86* record, columns 46-52) and, if the user provided it, the point's designation (*80* record, columns 15-44).

The format and content of the *94* records in the Blue Book format output file will be the same, whether the input file was Blue Book or Free Format.

5.2 Free Formatted Output

If the user chooses Free Format output, then this file consists of one record per point transformed (i.e. not clipped for being outside the region of choice), containing the transformed coordinates and the quality indicator of that transformation. If the user gave a Free Format input file, then this output file will follow the "type" (1-12, see section 4.2) of the *last* record found in the input file, but each record will have 5 additional fields (representing the "quality" of the transformation) following the "designation" field.

If the user provided a Blue Book Format input file, then the Free Format output file will always be of type 3 (Comma Delimited, With Hemisphere Identifiers, Degrees/Minutes/Seconds -- see section 4.2) containing latitude, longitude, ellipsoid height, (possibly) designation and the quality indicators.

5.3 Quality Information

Without regard for the format of the output file, each transformed record will contain 5 fields which describe the "quality" of the transformation. Those five fields are:

1) Latitude quality in arcseconds
2) Latitude quality in centimeters
3) Longitude quality in arcseconds
4) Longitude quality in centimeters
5) Ellipsoid height quality in centimeters

If the user requests Blue Book Format for their output file, then this information will be contained in the *94* record. The format of this new record is described fully in Section 11. If the user requested Free Format for their output file, then these 5 fields will be appended to the end of the record for each transformed point, using either comma or space delimiters as appropriate.

The quality indicators in latitude, longitude, and height are obtained through biquadratic interpolation from the associated transformation quality grids. Those grids were obtained by fitting splines in tension to sets of worst-case cross-validation errors in the various regions.

Also note that the reported transformation quality values are *signed* quantities. These are reported in the sense of: actual coordinate difference – gridded coordinate difference. The transformation quality indicators should be treated as systematic error. One should add the absolute value of the quality indicator to the network accuracy of the pre-transformed point. A coordinate transformation never improves the quality of the underlying data. For further information, see Part II, Section 5 of this manual.

6. The Output Clip File

The clip file contains copies of input records for any points that fall outside the selected region, using the format of the input file. If all input points are within the selected region, the clip file will be empty. The number of records in the clip file plus the number of records in the output transformed point file should equal the number of records in the input file.

Note that if the input file has points from a mixture of regions, then one may use the generated clip file as input to a subsequent run of GEOCON with a different selected region. In this way, one may easily transform all the input points.

7. The Output Notification File

This file contains supplemental information that may explain the source of certain large quality indicators. This information is not issued for *all* instances of large quality indicators, however. Rather, it is issued only when:

a) A large (> 5 cm) quality indicator has occurred for a transformation in latitude or longitude or ellipsoid height, and
b) A cluster of points is nearby (< 5 km), and one member of that cluster is a worst-case contributor to the transformation quality grid, and
c) That same point (b) was not used in the transformation grid.

In this way, the user is warned that a particularly erroneous point is nearby, and that the reason they are seeing such a large localized quality indicator might be due to this outlier. This information is issued to help users understand that the transformation grid (which is *not* based on outliers, but rather is representative of the *well-behaved* points) will be a poor tool for any surveys which had the misfortune of tying into the erroneous local point (since such a point is *not* reflected in the transformation grid). As GEOCON has no information about whether the user has or has not tied to the erroneous point, it issues both a large quality indicator in this area and a notification to the user.

For example, consider the transformation of:

```
003480*80*5084NOT METOMEN GPS                 40115697143N104433324639W 31273AWIBA
      *86*5084   312725A  N88       -35761W  1503844A32A
```

This generates a transformation quality record:

```
      *94*5084         0.00137      4.22   0.01766     41.66     -9.54
```

Where one can see sizable longitude and ellipsoid height quality indicators (41.66 cm and -9.54 cm).

The notification file issues these two messages:

```
Large (  41.66 cm) LON qual. value near  40.1991587306 ,  255.2740982250 might be
caused by nearby pt LL1465 whose LON shift of   55.63 cm was not part of the
transformation grid

Large (  -9.54 cm) EHT qual. value near  40.1991587306 ,  255.2740982250 might be
caused by nearby pt LL1477 whose EHT shift of  -12.56 cm was not part of the
transformation grid
```

Thus, one can see the longitude transformation quality of 41.66 cm was likely due to the point LL1465 being nearby and having a longitude difference [NAD 83(NSRS2007) minus NAD 83("HARN")] that was in such poor agreement with neighboring longitude differences as to be a worst-case outlier relative to those other nearby points. Similarly the ellipsoid height transformation quality of -9.54 cm was likely due to a similar ellipsoid height problem at nearby point LL1477.

Notification file messages are informational in nature: there is no specific action a user need take due to them. However, if the transformation quality indicator exceeds the user's desired error budget, then the user is strongly encouraged to investigate exactly how their input data were connected to the geodetic control network.

Notification messages are generated from information in the info files that come with GEOCON. Their format is described below in Section 8.2, "Format of ASCII info files". The information files are plain ASCII files that list those worst-case points that are members of clusters and exceed a certain threshold. These points were dropped when creating the coordinate transformation grids, yet they did have published coordinates in both NAD 83("HARN") and NAD 83(NSRS2007), and thus may have been used in the field. As such, their published, yet outlier nature, causes them to give a "notification" whenever a user is using GEOCON to transform coordinates nearby.

8. GEOCON Support Files

In order for GEOCON to function, the following binary grid files and ASCII info files must be available to the program:

Name	File Type	Description	Region
dela.b	binary grid	"quality" indicator, latitude	CONUS
delaa.b	binary grid	"quality" indicator, latitude	Alaska
delap.b	binary grid	"quality" indicator, latitude	PR/VI
delo.b	binary grid	"quality" indicator, longitude	CONUS
deloa.b	binary grid	"quality" indicator, longitude	Alaska
delop.b	binary grid	"quality" indicator, longitude	PR/VI
dev.b	binary grid	"quality" indicator, ellipsoid height	CONUS
deva.b	binary grid	"quality" indicator, ellipsoid height	Alaska
devp.b	binary grid	"quality" indicator, ellipsoid height	PR/VI
dsla.b	binary grid	coordinate transformation, latitude	CONUS
dslaa.b	binary grid	coordinate transformation, latitude	Alaska
dslap.b	binary grid	coordinate transformation, latitude	PR/VI
dslo.b	binary grid	coordinate transformation, longitude	CONUS

dsloa.b	binary grid	coordinate transformation, longitude	Alaska
dslop.b	binary grid	coordinate transformation, longitude	PR/VI
dsv.b	binary grid	coordinate transformation, ellipsoid height	CONUS
dsva.b	binary grid	coordinate transformation, ellipsoid height	Alaska
dsvp.b	binary grid	coordinate transformation, ellipsoid height	PR/VI
infoa.txt	ASCII text	info file for notifications, latitude	CONUS
infoaa.txt	ASCII text	info file for notifications, latitude	Alaska
infoap.txt	ASCII text	info file for notifications, latitude	PR/VI
infoo.txt	ASCII text	info file for notifications, longitude	CONUS
infooa.txt	ASCII text	info file for notifications, longitude	Alaska
infoop.txt	ASCII text	info file for notifications, longitude	PR/VI
infov.txt	ASCII text	info file for notifications, ellipsoid height	CONUS
infova.txt	ASCII text	info file for notifications, ellipsoid height	Alaska
infovp.txt	ASCII text	info file for notifications, ellipsoid height	PR/VI

8.1 Format of binary grids

These input files are unformatted files, written as FORTRAN unformatted sequential files. As such, these FORTRAN records automatically contain prefix and suffix information that indicate the lengths of each record. The binary files were created on a PC, and have the "little-endian" representation of x86 architectures. The binary grid files are provided by NGS. They are a legacy form that has been used internally.

The first record of a binary grid file is a header record containing 7 elements which georeferences the remaining grid data.

<u>Header record elements are:</u>

Element	**Description**	**Units**	**Bytes**
glamn	geodetic latitude of SW corner of grid	degrees	8 byte floating point
glomn	geodetic longitude of SW corner of grid	degrees	8 byte floating point
dgla	spacing of grid in latitude	degrees	8 byte floating point
dglo	spacing of grid in longitude	degrees	8 byte floating point
nla	number of rows in grid	unitless	4 byte integer
nlo	number of columns in grid	unitless	4 byte integer
ikind	Describes type of data in the grid: = 0 means 4 byte integer = 1 means 4 byte floating point	unitless	4 byte integer

Note that for the GEOCON files, ikind = 1 has been used throughout.

<u>Grid records:</u>

Each record corresponds to a row in the geographic raster grid. Thus, one will always have exactly "nla" unformatted sequential records. Each record will contain exactly "nlo" elements. And, since ikind = 1 for the GEOCON grids, each element will be a single precision (32 bit) floating point value.

Records are written sequentially from South to North. And, within each record, the elements are written sequentially from West to East (row major, column minor order). Thus, all the elements of the first row correspond to the geodetic latitude of glamn. Elements of the second row correspond to latitude glamn + dgla, and so on. Similarly, the first element of any given row corresponds to a geodetic longitude of glomn. The second element corresponds to a longitude of glomn + dglo, and so on. One may see that the maximum latitude of the grid is [glamn + (nla – 1) × dgla]. And, the maximum longitude of the grid is [glamn + (nla – 1) × dgla].

Each element corresponds to the exact latitude and longitude implied by the row and column order in the set of sequential records. There are no cells, nor is there any registration to a cell corner. The elements are associated to an exact point. Of course, grid elements may be point values, or they may be obtained from some area averaging process.

For all coordinate shift grids, the shift is stored as [NAD 83(NSRS2007) - NAD 83(HARN)]. For GEOCON11, the shift is stored as [NAD 83(2011) – NAD 83(NSRS2007)]. For all "quality" grids, the "quality" is stored as actual coordinate difference minus gridded coordinate difference. Latitudes are considered positive North, longitudes are positive East, and ellipsoid heights are positive up. For latitude and longitude, the shifts and quality indicators are in units of 0.00001 arc seconds. For heights, the shifts and quality indicators are in units of 1 cm.

8.2 Format of ASCII info files

These input records are standard ASCII text with fixed column formatting. They are provided by NGS. Each record represents a point in the NGS Integrated Database (NGS IDB) which had both a published NAD 83("HARN") coordinate set and an NAD 83(NSRS2007) coordinate set, where the differences between these two coordinate sets at that one point were abnormally "large" when compared to the median of the same differences at neighboring points. For GEOCON11, these coordinate sets would be NAD 83(NSRS2007) and NAD 83(2011). Information records are used to generate the GEOCON notification messages, purely as a warning that a user is performing transformations near an anomalous point whose values were not used in creating the coordinate transformation grid, but which nonetheless exists and has published values. The data in each record can be identified by columns, as follows:

Columns	Description	Example	FORTRAN format
01 to 15	Longitude of point, positive East, degrees	99999.999999999	f15.9
16 to 30	Latitude of point, positive North, degrees	99999.999999999	f15.9
31 to 40	Value (see below)	9999999.99	f10.2
42 to 47	PID (NGS Permanent Identifier)	AA0000	a6

Note: Value represents the difference between the *actual* coordinate shift (based on the published coordinates of the point) and the *predicted* coordinate shift (obtained from biquadratic interpolation from the gridded coordinate shifts of "good" points). Units of

“Value” are 0.00001 arc seconds for latitude and longitude information files, and 1 cm for ellipsoid height information files.

Example (fragment from **`infoa.txt`**):

```
 271.883038767   30.735019717   -204.23 BH3164
 271.861424622   32.837918328    281.43 CO1586
```

9. Format of Blue Book *80* Control Point Record

This section is provided as a summary for those users who opt to use Blue Book Format as their input or output file.

These records are standard ASCII text with fixed column formatting. They are a legacy format more fully described in Chapter 2, Horizontal Observation (HZTL OBS) Data, of the Input Formats and Specifications of the National Geodetic Survey Data Base (the FGCS Blue Book), Volume I - Horizontal Control. This information is available online at http://www.ngs.noaa.gov/FGCS/BlueBook/

GEOCON only considers columns 7 through 14 and 45 through 69 of this format.
It is possible to not fill the remaining fields at all, or to fill them with alternative information.

GEOCON requires the input file to consist solely of *80* and *86* records, entered pairwise. That is, *80* will always be the odd numbered records, and *86* records will always be the even numbered records. And any given *86* record will be associated with the horizontal position of the *80* record immediately preceding it.

CC 01-06	SEQUENCE NUMBER. OPTIONAL. RIGHT JUSTIFIED. INCREMENT BY 10 FROM THE PREVIOUS RECORD.
CC 07-10	DATA CODE. MUST BE *80*.
CC 11-14	SSN. SEE PAGES 1-1, JOB CODE AND SURVEY POINT NUMBERING AND 2-12, ASSIGNMENT OF STATION SERIAL NUMBERS.
CC 15-44	STATION NAME. MUST NOT EXCEED 30 CHARACTERS. THE NAME OF A HORIZONTAL CONTROL POINT WITH PERIPHERAL REFERENCE MARKS AND/OR AZIMUTH MARKS MUST NOT EXCEED 24 CHARACTERS TO ALLOW FOR ADDING RM 1, RM 2, AND/OR AZ MK TO THE NAME WITHOUT EXCEEDING THE 30-CHARACTER LENGTH LIMIT.
CC 45-55	LATITUDE. DEGREES, MINUTES, SECONDS (DDMMSSsssss).
CC 56	DIRECTION OF LATITUDE. RECORD CODE "N" FOR NORTH OR CODE "S" FOR SOUTH.
CC 57-68	LONGITUDE. DEGREES, MINUTES, SECONDS, (DDDMMSSsssss).
CC 69	DIRECTION OF LONGITUDE. RECORD CODE "E" FOR EAST OR CODE "W" FOR WEST.

THE *86* RECORD IS TO BE USED FOR THE ELEVATION (ORTHOMETRIC HEIGHT) AND ELEVATION CODE, WHICH WERE FORMERLY DISPLAYED IN THE FOLLOWING TWO FIELDS.

CC 70-75 BLANK.
CC 76 BLANK.
CC 77-78 STATE OR COUNTRY CODE. IF THE CONTROL STATE IS LOCATED IN THE UNITED STATES/CANADA, ENTER THE CODE FROM ANNEX A FOR THE STATE/PROVINCE OR TERRITORY WHICH CONTAINS THE STATION. IF NOT, ENTER THE CODE FROM ANNEX A FOR THE COUNTRY WHICH CONTAINS THE STATION. SEE ANNEX A.
CC 79-80 STATION ORDER AND TYPE. REFER TO PAGES 2-35 THROUGH 2-38, STATION ORDER AND TYPE AND SEE ANNEX E.

Example:

```
003650*80*5120FRIENDSHIP S GPS      43500699703N088295718725W 24000KWI1A
      *86*5120    240003K N88 -35880W     204115A32A
003660*80*5121VAN DYNE GPS    43521622332N088301532627W 24358KWI1A
      *86*5121    243581K N88 -35960W     207618A32A
```

10. Format of Blue Book *86* Orthometric Height, Geoid Height, Ellipsoid Height

This section is provided as a summary for those users who opt to use Blue Book Format as their input or output file.

These records are standard ASCII text with fixed column formatting. They are a legacy format more fully described in Chapter 2, Horizontal Observation (HZTL OBS) Data, of the Input Formats and Specifications of the National Geodetic Survey Data Base (the FGCS Blue Book), Volume I - Horizontal Control. This information is available online at http://www.ngs.noaa.gov/FGCS/BlueBook/

GEOCON only considers columns 7 through 10 and 46 through 52 of this format.
It is possible to not fill the remaining fields at all, or to fill them with alternative information.

GEOCON requires the input file to consist solely of *80* and *86* records, entered pairwise. That is, *80* will always be the odd numbered records, and *86* records will always be the even numbered records. And, any given *86* record will be associated with the horizontal position of the *80* record immediately preceding it.

CC 01-06 SEQUENCE NUMBER. OPTIONAL. RIGHT JUSTIFIED. INCREMENT BY 10 FROM THE PREVIOUS RECORD.
CC 07-10 DATA CODE. MUST BE *86*. CC 11-14 SSN OF CONTROL POINT.
CC 15-16 BLANK
CC 17-23 ORTHOMETRIC HEIGHT. IN METERS (MMMMmmm).
CC 24 ORTHOMETRIC HEIGHT CODE. SEE FOLLOWING TABLES.
CC 25-26 ORTHOMETRIC HEIGHT ORDER AND CLASS. USE PUBLISHED VERTICAL ORDER AND CLASS, OTHERWISE LEAVE BLANK.
CC 27 ORTHOMETRIC HEIGHT NGSIDB INDICATOR. SEE FOLLOWING TABLES.
CC 28-29 ORTHOMETRIC HEIGHT DATUM. SEE FOLLOWING TABLES.

CC 30-35 ORGANIZATION WHICH ESTABLISHED AND/OR MAINTAINS THE ORTHOMETRIC HEIGHT OF THE CONTROL POINT. ENTER THE ABBREVIATION LISTED IN ANNEX C OR ON THE DATASET IDENTIFICATION RECORD.
CC 36-42 GEOID HEIGHT. ABOVE (POSITIVE) OR BELOW (NEGATIVE) THE REFERENCE ELLIPSOID. IN METERS (MMMMmmm).
CC 43 GEOID HEIGHT CODE. SEE FOLLOWING TABLES. CC 44-45BLANK.
CC 46-52 ELLIPSOID HEIGHT. IN METERS (MMMMmmm).
CC 53 ELLIPSOID HEIGHT CODE. SEE FOLLOWING TABLES. CC 54-55 ELLIPSOID HEIGHT ORDER AND CLASS. SEE ANNEX G. CC 56 ELLIPSOID HEIGHT DATUM. SEE TABLE, P. 2-85.
CC 57-80 COMMENTS.

Example:

```
003650*80*5120FRIENDSHIP S GPS        43500699703N088295718725W 24000KWI1A
*86*5120        240003K N88 -35880W        204115A32A
003660*80*5121VAN DYNE GPS   43521622332N088301532627W 24358KWI1A
*86*5121        243581K N88 -35960W        207618A32A
```

11. Format of *94* Transformation Quality Record

If the user asks for Blue Book Format for the output file, then the transformation quality information will be contained in *94* records, with one such record for each transformed point. Each *94* record will follow the pair of *80* and *86* records for the transformed point.

These output records are standard ASCII text with fixed column formatting. While they follow the general structure of the HZTL OBS Blue Book, they are not officially Blue Book records. The Station Serial Number (SSN) of this record is obtained from the ASCII contents of columns 11 through 14 of the input *80* record.

This record expresses the quality of the coordinate transformation by use of cross- validation errors. In cases of clusters, the worst-case error is reported. These values should be used to increase the base network accuracy of the pre-transformed coordinates.

cc 01-06 Sequence number. Optional, see Blue Book
cc 07-10 Data Code. Must be *94*
cc 11-14 SSN. See Blue Book
cc 15-20 BLANK
cc 21-30 Latitude Error, arc-sec 9999.99999 (f10.5)
cc 31-40 Latitude Error, cm9999999.99 (f10.2)
cc 41-50 Longitude Error, arc-sec 9999.99999 (f10.5)
cc 51-60 Longitude Error, cm 9999999.99 (f10.2)
cc 61-70 Ellipsoid Height Error, cm 9999999.99 (f10.2)

Example:

```
*94*5014          0.00006      0.18   0.00001      0.03     -0.19
```

If the user has requested Free Format for their output file, then the quality indictors will be appended to the end of each record for each transformed points.

II. Technical Details

1. Introduction

This section of the GEOCON manual provides further technical details about the *creation* of the programs GEOCON (v1.1) and GEOCON11 (v1.1) which is not necessarily part of the *operation* of the program itself. Because GEOCON and GEOCON11 have so many similarities, this document will restrict itself to discussion of GEOCON, and the reader may assume that similar details exist for GEOCON11 unless explicitly stated otherwise.

2. Coordinate Transformation

During the operation of GEOCON, each specific transformation (latitude, longitude or ellipsoid height) is obtained through biquadratic interpolation from the associated coordinate transformation grid (latitude, longitude, and height). Those grids are provided as part of GEOCON and were created by fitting splines in tension to sets of coordinate differences in the various regions. In cases of clusters of points that fell within 1' x 1' cells, a (modified) median filter (see section 4) was used to select the point passed to the spline model. More detail on the fitting process may be found in the GEOCON Users Guide.

The coordinate sets, both NAD 83("HARN") and NAD 83(NSRS2007), are defined quantities (as of a particular date). Good or bad, the coordinate differences between NAD 83("HARN") and NAD 83(NSRS2007) are constants[6]. There can be no expectation of smoothness in a coordinate transformation. Plots of high-resolution coordinate transformations may not look pleasing. Blunders in the coordinates in an older realization of NAD 83 that are corrected in the newer realization will appear as abnormal shifts. But, they are not to be excluded from consideration. They are actual differences between two published coordinate sets.

To support our user communities, NGS decided to create a coordinate transformation between the NAD 83("HARN") and the NAD 83(NSRS2007). This, in turn, implies seeking a mathematical mapping between the two coordinate sets, irrespective of their values. The program which performs this transformation is GEOCON. Its companion, GEOCON11, performs similar transformations between NAD 83(NSRS2007) and NAD 83(2011).

3. Coordinate Differences: Between the Points

One could argue that a coordinate transformation only exists at the points that define the coordinate differences. While being a legitimate argument, such a perspective would provide no guidance on how to treat intervening points that were directly or indirectly tied to the defining coordinates. For guidance we must consider field practice. And, this practice will not just include surveyors, but all practitioners who create georeferenced data sets.

[6] Occasionally errors are found and corrected or new surveys improve the coordinate of a point. In these cases a point's NAD 83("HARN") or NAD 83(NSRS2007) coordinates may be superseded. But from a general, nationwide standpoint, the differences between NAD 83("HARN") and NAD 83(NSRS2007) are constant. The same may be said about NAD 83(NSRS2007) and NAD 83(2011) coordinate differences.

It is natural to define the coordinate transformation between defining points as being an intermediate value. As such, one does not want to see extraneous oscillations in a transformation function, even when there are large, local excursions at the defining points. In essence, one wishes to “connect the dots”.

To satisfy the needs of honoring the data and generating intermediate values, the method of gridding splines in tension (Smith and Wessel, 1990) was chosen. This models the physical behavior of a thin, flexible plate that passes through the defining points. However, such a model, by itself, is subject to overshoots and undershoots when data differences occur near gaps in irregularly spaced data. By mathematically applying tension at the edges of a grid, it is possible to suppress the oscillations, and generate representative intermediate values. For GEOCON, after some tests, a 1’ x 1’ grid with a tension parameter of 0.4 was selected.

Basically, the fitted grid is modeling the coordinate differences a practitioner would obtain when performing two different least squares adjustments of the same survey data when controlled by two different control point coordinate sets. Alternatively, one may consider that the transformation grid models the differences for photogrammetric data, or synthetic aperture radar, or LIDAR, or any other coordinate measurement system that ties to the control point coordinate set.

If, however, a practitioner only performs a single point tie, then all of the geospatial data should be transformed by the unique coordinate difference of the source control point.

Consider an extreme example; the ellipsoidal height for the point **M 123** (PID=TT2413) as obtained from the NGS database in November 2011 (Appendix A.1.):

NAD 83(“HARN”) ellipsoidal height:	486.945 meters	(06/20/05)
NAD 83(NSRS2007) ellipsoidal height:	641.786 meters	(07/17/09)

The (admittedly extreme) change of nearly 155 meters is due to the re-measurement and readjustment of **M 123**.

Now suppose a practitioner has some regional data in an NAD 83(“HARN”) coordinate set. If the data are tied to the abnormal point **M 123** *and* other nearby control points with much smaller coordinate differences then the ellipsoidal height coordinate differences will get larger and larger for the data points *nearer and nearer* **M 123**. On the other hand, if the practitioner connected the work *solely* to **M 123**, then *every* ellipsoidal height must be increased by exactly 154.841 meters irrespective of the distance from **M 123**.

This is one reason why the National Geodetic Survey considers actual recomputation of geospatial data, and not coordinate transformations, as “best practice”. The coordinate transformation is, at its heart, only a model of actual geospatial measurement and processing and cannot replace the practice of beginning with new, better geodetic control coordinates and reprocessing original survey measurements from that new control.

4. Coordinate Differences: Modified median filter

The analysis of the NAD 83(NSRS2007) National Readjustment (Milbert 2008) showed a number of surprising results. One was the highly local character of the network. Over 50%

of all GPS vectors were 31 km or less in length. Figure 5.3 of Milbert (2008, pg. 12) is reproduced below as Figure 4.1. Note the significant number of GPS vectors of just 1 or 2 km in length.

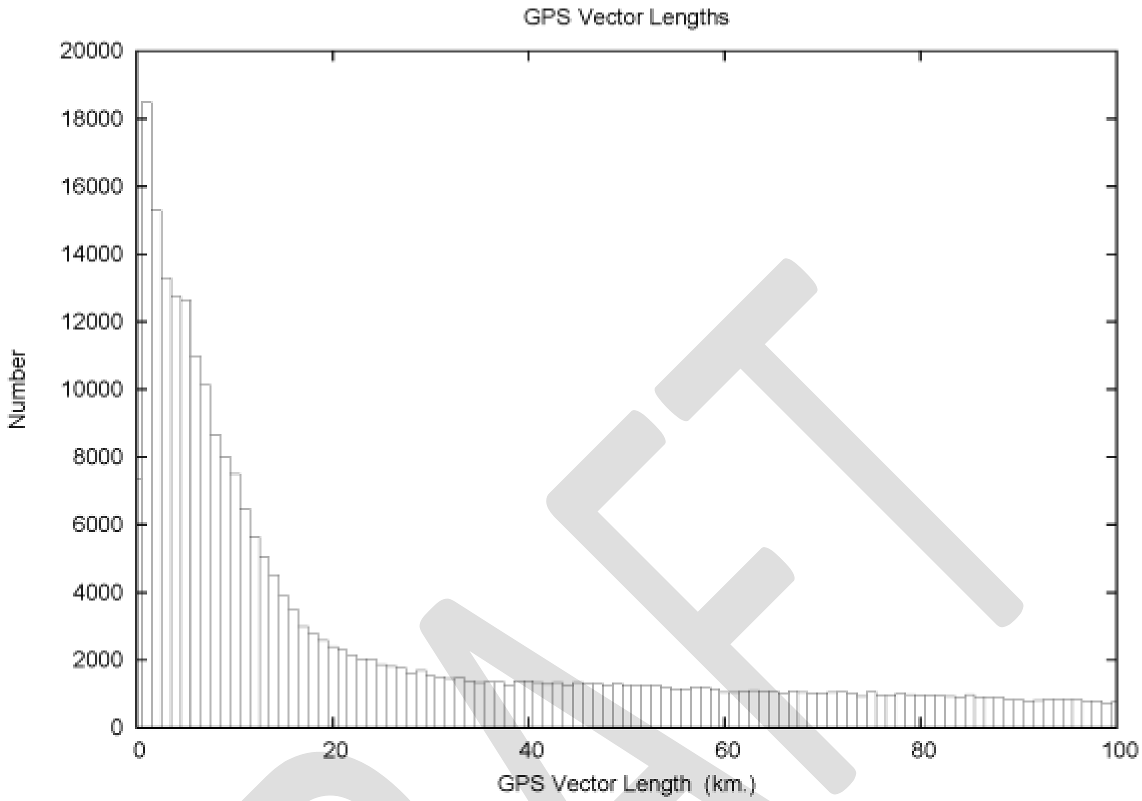


Figure 4.1. Distribution of GPS vector lengths, 0 to 100 km. 1 km bin size.

Even though a grid size of 1’ x 1’ was selected to model the coordinate differences, it can be expected that there will be clusters of defining points at some of the grid nodes. This is because of the close spacing of some of the control points. This naturally raises a question: How can one “honor the data” for multiple coordinate differences near a grid node?

It was decided to select the most representative control point by means of a median filter, albeit with some modifications. The median value of a set is the value that delimits the higher half and lower half of the set. It can be obtained by sorting the set and choosing the middle value. In the case of an even number of points, the mean of the two central points is reported. The advantage of the median is that it is a robust estimate when more than two data are present. An outlier does not disturb the median.

To increase the robustness in GEOCON, a modified median procedure was used prior to gridding. In the case of a cluster of exactly 2 points, a search was performed in the 1’ to 2’ ring surrounding the central 1’x1’ cell. If the search found a point, it was used as a tiebreaker to select the winning median point in the central cell. If the 1’ to 2’ ring was insufficient, then the 2’ to 3’ ring was searched for a tiebreaker. If, after two ring searches no tiebreaker was found, then the central cell median was selected at random from the 2 available points. It was found that that the ring search procedure was able to reduce 8177 pairs to 1534 pairs. And, by using a random selection, the possibility of the median being influenced by an abnormal point in the pair is additionally halved.

The philosophy in choosing a median procedure is rooted in the likely practice of geospatial professionals. In the presence of a cluster of control points, connections should be made to a sufficient number to confirm the connection to the control network. Depending upon the accuracy of the positioning measurements, significant discrepancies may be identified. And, ties to suspect control points would be discarded. This is standard practice in surveying.

5. Transformation Quality

Significant thought and effort were put into answering the question of how best to describe the quality of the transformation which GEOCON is providing to the user. The preceding two sections illustrate the reasons why this question is so challenging to answer.

Specifically:

- It is possible that georeferenced data may be tied to control points with *both standard* coordinate differences and *abnormal* coordinate differences, or

- It is possible that georeferenced data may be tied *solely* to control points with *standard* coordinate differences, but be *near* points with *abnormal* coordinate differences, or

- It is possible that georeferenced data may be tied *solely* to control points with *abnormal* coordinate differences, but be *near* points with *standard* coordinate differences.

GEOCON receives *no* information which may help distinguish which of these situations have affected the points being transformed.

Further, there can be highly variable scale. "Near" may refer to spacing of a few hundred meters or a few hundred kilometers. "Standard" and "abnormal" may refer to coordinate differences of less than a millimeter to over 100 meters. User accuracy requirements may vary from millimeter to multi-meter network accuracy, and may address only horizontal or only vertical components.

Because of the lack of information about the input data, it was decided that GEOCON would issue highly conservative "quality indicators", based on the worst-case scenario which a user might encounter. To summarize:

- GEOCON <u>transformations</u> are based on *median* values, reflecting points that are highly representative of their neighbors

- GEOCON <u>quality indicators</u> are based on the *worst-case* values, reflecting points that least match their neighbors.

To arrive at the worst-case values, upon which the quality indicators were created, a statistical resampling procedure known as cross-validation was selected. Cross-validation is useful in assessing predictive models (Efron and Tibshirani, 1998). It is appropriate to consider coordinate transformation as an exercise in prediction. The NGS database of coordinates with multiple coordinate realizations represents prior knowledge. Other practitioners, whose data are never known to NGS, will establish coordinates traceable to the NGS database. We seek to predict the transformed coordinates from those unknown coordinates.

In its simplest form, cross-validation consists of cutting a data set in half. Call the first half the training set, and build the prediction model from the first half. Then compare the second half of the data, called the validation or testing set, to the model predictions. Similarly, one may exchange the two data halves, and repeat the process.

In the extreme case, one can imagine taking a set of data, withholding a single data point, producing a unique model, and then computing the difference between the single withheld data point and the model. And, one can imagine doing this sequentially for every single point in the data set. This method is known as the jackknife (Efron 1979).

Obviously, the jackknife can entail a large computational burden for sizable data sets. However, there is a middle ground. One can compute K-fold cross-validation (Efron and Tibshirani, ibid), where the data set is partitioned into K subsets. In sequence, each subset is designated as a testing set, and is temporarily withheld from the data set. The model is computed from each reduced data set, and differences are computed between the temporarily withheld data and the model prediction. The process is sequenced K times until a prediction error is established for each data point.

For GEOCON a 69-fold cross-validation was performed. The master data set was 69540 point pairs. So each testing subset was a little over 1000 points. This means 69 training grids were computed for each coordinate type (latitude, longitude or ellipsoid height), for the regions of CONUS, Alaska, and Puerto Rico/Virgin Islands. The 207 training grids for CONUS took about 8 hours to compute. The result was a set of cross-validation errors for the coordinate differences in latitude, longitude, and ellipsoid height.

The appeal of cross-validation error is that it quantifies the abnormality of a point relative to its neighbors. Consider the case of point **M 123** again. The ellipsoid height coordinate difference [NAD 83(NSRS2007) minus NAD 83("HARN")] is +154.797 meters. The cross-validation error is +154.8192 meters, showing that the point is definitely abnormal when compared to its neighbors.

The worst-case cross-validation errors were gridded, and these grids compose the "quality indicator" grids of GEOCON. By interpolating from these grids, GEOCON is able to provide to the user a "quality indicator", which quantifies the localized *maximum* uncertainty associated with varying field procedures and processing. If one is in the midst of normal control points, then the localized cross-validation errors will tend to be small. As one approaches an abnormal point, the quality indicator will get larger, indicating increasing uncertainty about the proper coordinate transformation value to use.

For the case of a cluster of points, it is important to reflect the possibility that one of the points may be abnormal. Recall, when gridding the coordinate differences, a modified median procedure was used to select which points would be used when creating the actual *transformation* grids. That procedure dropped abnormal points in clusters. For the transformation *quality* grids, the median is *not* used. Rather the worst case cross-validation error in a cluster is gridded. The worst case is selected by choosing the error that is furthest in magnitude from the median error (an "anti-median", if you will).

In this way, the coordinate transformation grids of GEOCON provide the most likely transformations to apply to geospatial data, while, the transformation quality grids give a conservative idea of the magnitude of error which might affect transformation.

6. An Example in Northeast Colorado

It is useful to consider some raw coordinate data and its conversion into grids as illustration. Consider a region in northeast Colorado (Figure 6.1):

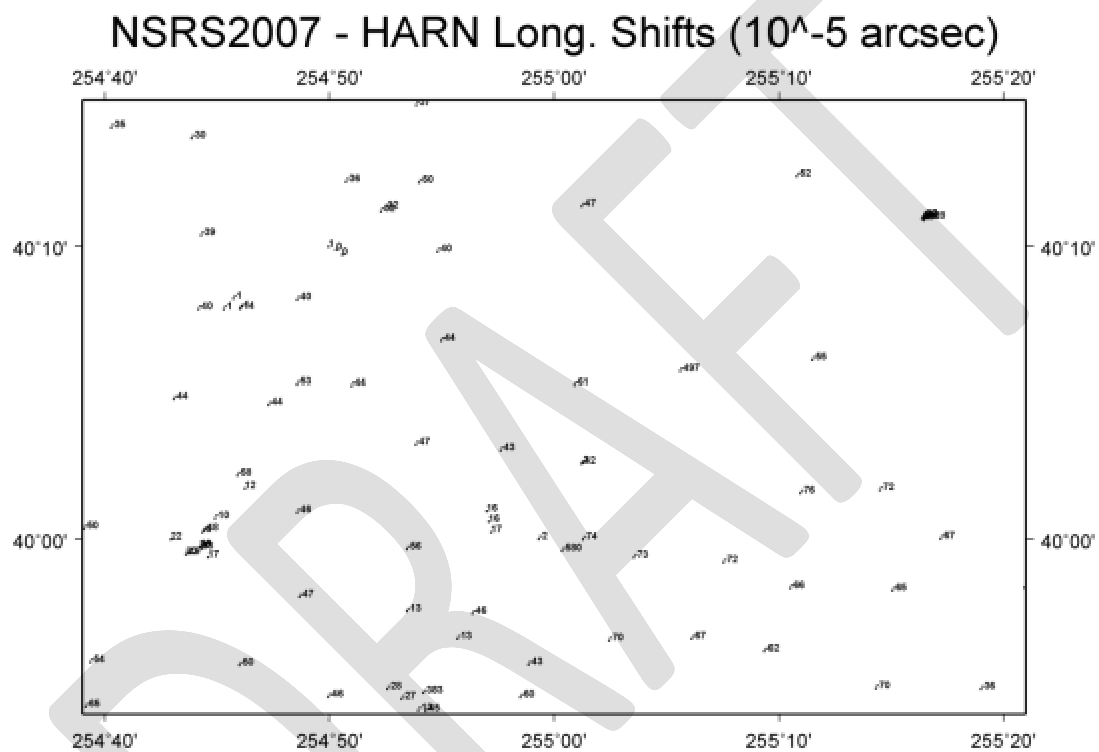


Figure 6.1. Longitude Coordinate Differences, Northeast Colorado.

To aid in discussion, the permanent identifiers (PID) of the points are displayed in Figure 6.2. The values portrayed in Figure 6.1 are the coordinate differences in longitude taken in the sense of NAD 83(NSRS2007) minus NAD 83("HARN"). In computing the shifts, the sense of the longitudes are positive East. The units are 0.00001 arc seconds. Thus, the numerical values in Figure 6.1 (as well as in subsequent figures) are integers. The small dots present near each number are the locations of the points. The small dots are not decimal points.

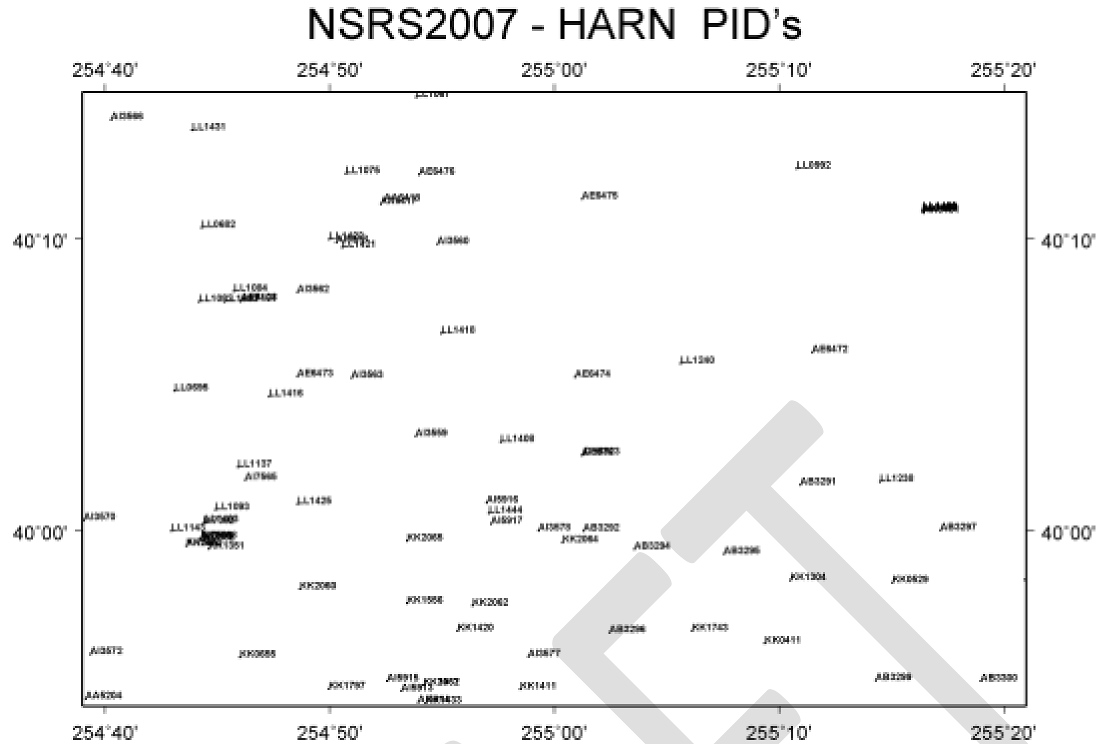


Figure 6.2. Permanent Identifiers (PID), Northeast Colorado.

Considerable variation in the coordinate longitude shifts is seen in Figure 6.1. However a nominal shift of about -0.00050 arc seconds is evident in most points. Close inspection of the shifts will show some abnormal values. In some cases, the points are clustered so tightly, it is impossible to resolve the numbers.

There are four abnormal longitude shifts of particular interest. These are plotted in Figure 6.3. And, their PID's are plotted in Figure 6.4. Recall from the earlier discussion, these are actual differences in the NGS database, and, most likely, subsequent surveys, maps, and other geospatial data have been controlled by both sets of coordinates. While they are abnormal in a regional sense, their existence and the possible reliance upon them by users over the years *must* be considered in a coordinate transformation.

Table 6.1 – Abnormal Longitude Coordinate Shifts

PID	Long. Shift (0.00001 arc sec)	Long. Shift (cm)
KK2067	-333	-7.8
KK2064	-580	-13.7
LL1240	-497	-11.8
LL1465	+2328	+55.1

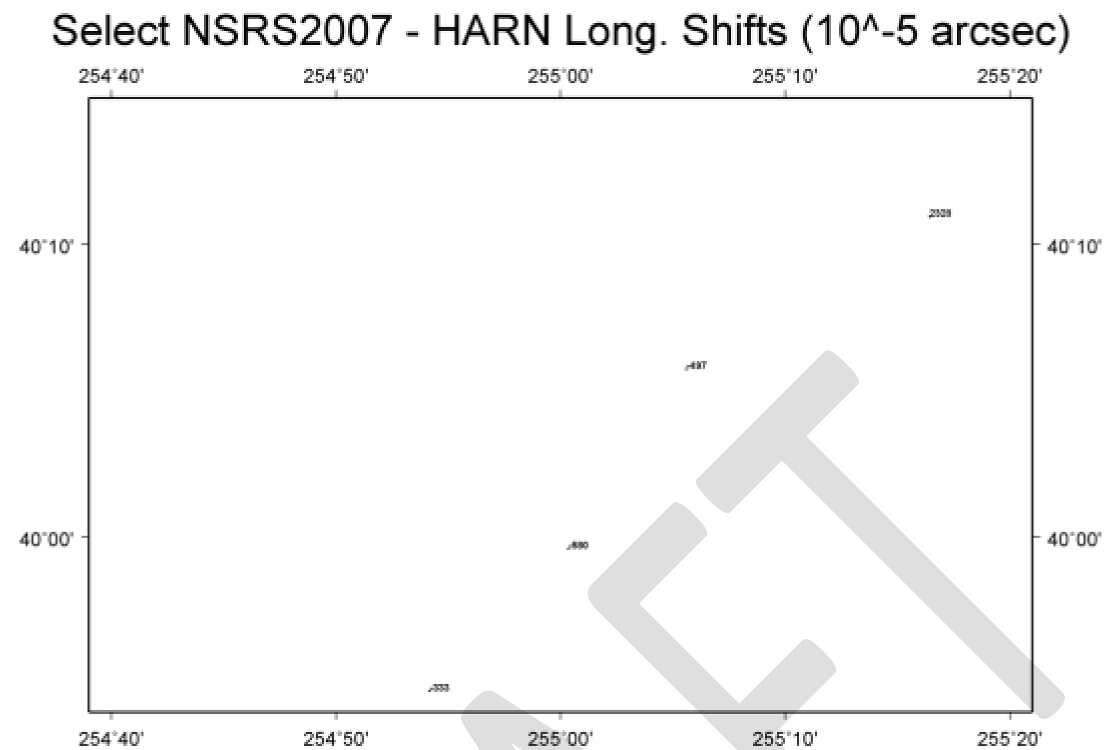


Figure 6.3. Abnormal Longitude Coordinate Differences, Northeast Colorado.

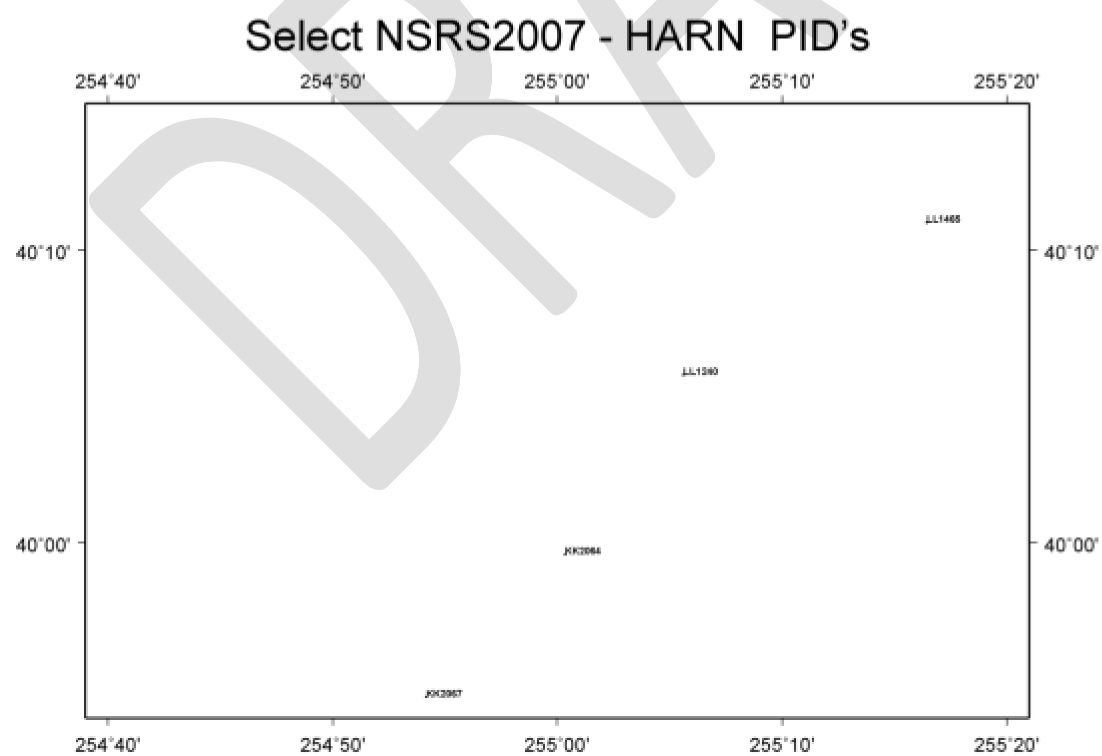


Figure 6.4. Permanent Identifiers (PID) of Abnormal Longitude Differences.

When the data in Figure 6.1 are run through a modified median filter and then gridded, we obtain the results portrayed in Figure 6.5. Once again, the units are 0.00001 arc seconds, the values displayed are integers, and the small dots represent grid nodes, and not decimal points.

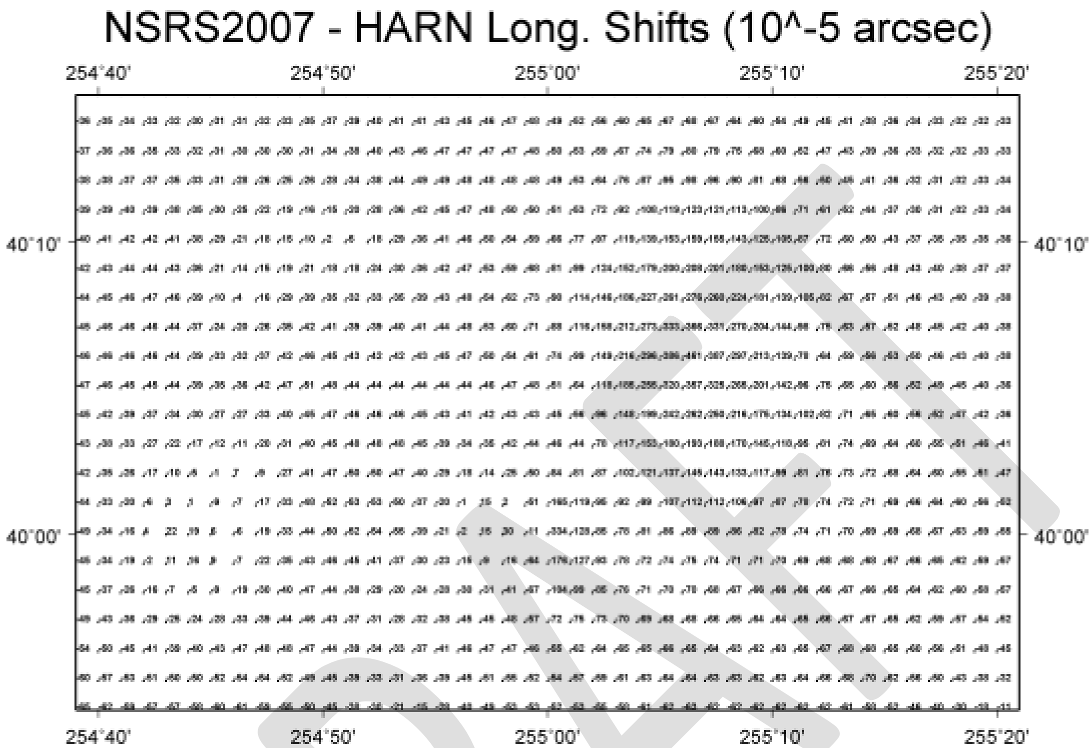


Figure 6.5. Gridded Longitude Coordinate Differences, Northeast Colorado.

We note that the 1’ x 1’ grid captures the general magnitude and nature of the coordinate shifts. It models the smaller shifts in the vicinity of 40º 00’ N, 254º 45’ E. Two of the four abnormal shifts (KK2064 and LL1240) are also evident as depressions in the grid. In particular, it is seen that the depression formed by LL1240 extends for some distance in all directions. This is because there are no neighbors nearby, and KK2064 and LL1240 were passed through the median filter prior to gridding and have become part of the transformation grid itself.

The use of this gridded transformation model will perform well if, for example, a local survey connects to LL1240 in addition to its neighbors: AE6472, AB3291, AB3295, AB3294, etc. One can see that a survey that solely connects to AE6472 (-0.00055 arc sec), but does not connect to LL1240 (-0.00497 arc sec), has a nominal longitude shift of - 0.00055 arc seconds. But as those local survey points approach LL1240, they will get progressively worse shifts. This situation must be reported to the coordinate transformation user. This is done by means of the transformation “quality indicator” grid.

In addition, while two of the abnormal shifts were modeled in the coordinate transformation grid[7], two other shifts were not (KK2067 and LL1465). These latter two points were in clusters *within* the 1’ x 1’ grid resolution, and *those* clusters contained more nominal values. As such, these two points were dropped by the modified median filter prior to the actual gridding. The points are plotted in Figure 6.6.

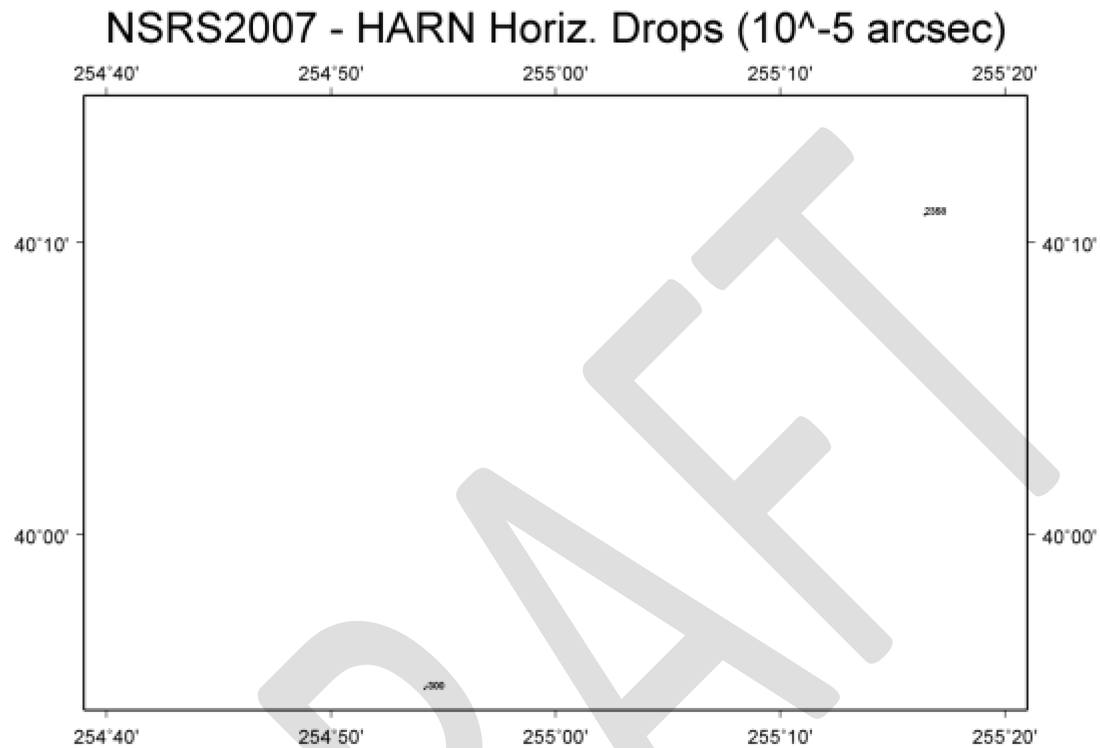


Figure 6.6. Abnormal Longitude Differences Dropped by Median Filter.

Note that the values in Figure 6.6 are not the actual longitude coordinate differences. Rather, they are the difference between the abnormal longitude differences of Figures 6.1 and 6.3, and the gridded longitude differences of Figure 6.5. Also note that the gridded values in Figure 6.5 are undisturbed by these abnormalities (since these points were dropped prior to gridding the transformations).

Once again, these abnormal quantities must be communicated to the coordinate transformation user, but the situation is different than the prior two abnormal points. It is assumed that local surveying, mapping, and other geospatial work will have made multiple connections to nearby points, and have detected the issues. So the filtered transformation grid represents the most likely situation. As discussed earlier, the situation is reported through the transformation quality grid.

[7] Which is to say that they were allowed to pass through the modified median filter prior to gridding because they did not have any/enough neighboring points to prevent it.

Figure 6.7 plots the cross-validation errors in the sense of true coordinate difference minus difference interpolated from the transformation grid, where the grid was obtained after dropping that specific point (and around 1000 other randomly selected points throughout the entire data set). As before, units are 0.00001 arc seconds, and longitudes are positive East. To assist in inspection, the cross-validation errors of the four abnormal points are shown in Figure 6.8.

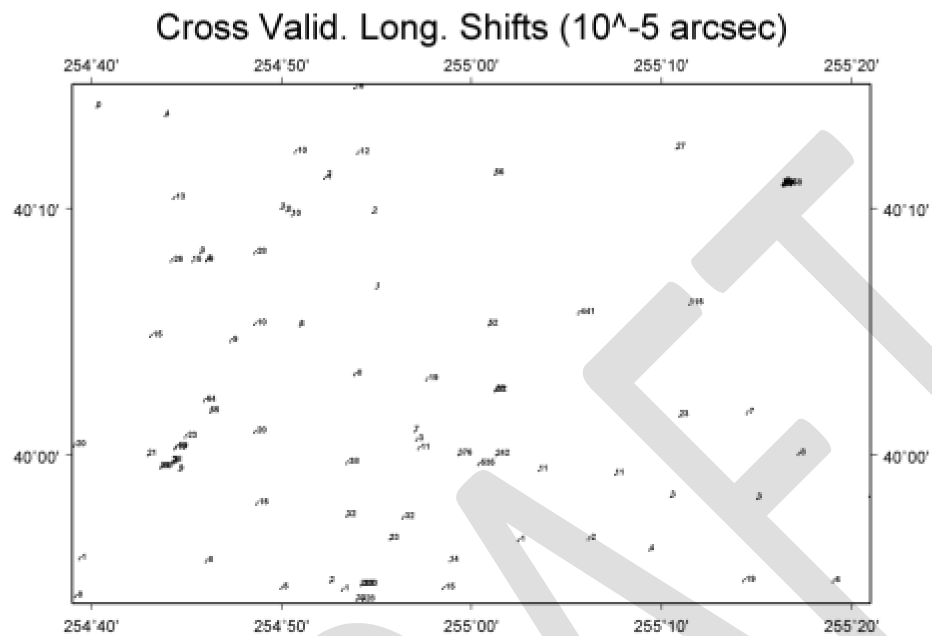


Figure 6.7. Cross-Validation Error of Longitude Coordinate Differences.

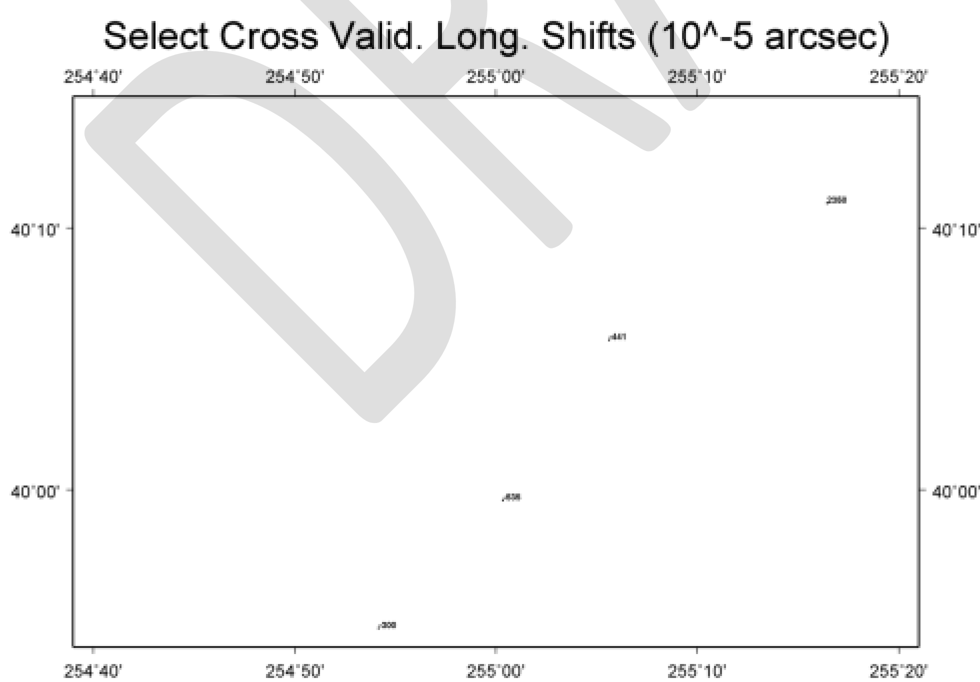


Figure 6.8. Abnormal Cross-Validation Error of Longitude Differences.

The first thing to be noticed in Figure 6.7 is that the nominal values of the cross- validation errors are typically much smaller than the nominal -0.00050 arc second longitude shift. This shows the grid (in general) is doing a very good job of predicting the coordinate shift at a point when that point was withheld from the gridding computation.

In addition, the cross-validation errors at the abnormal points do, indeed, look abnormal. They show the systematic characters of the quality value, including the sign of the value. For example, consider LL1465, with an actual longitude shift of +0.02328 arc seconds. The gridded transformation in Figure 6.5 is about -0.00030 arc seconds. So the systematic error for LL1465 is assessed at +0.02358 arc seconds.

Recall that the transformation quality grid is obtained by gridding the cross-validation error, and that abnormalities were dropped by a median filter. However, in the case of clusters of the cross-validation error, the worst-case error is passed to the gridding algorithm. This makes a distinct difference in the locations around KK2067 and LL1465. This is displayed in Figure 6.9.

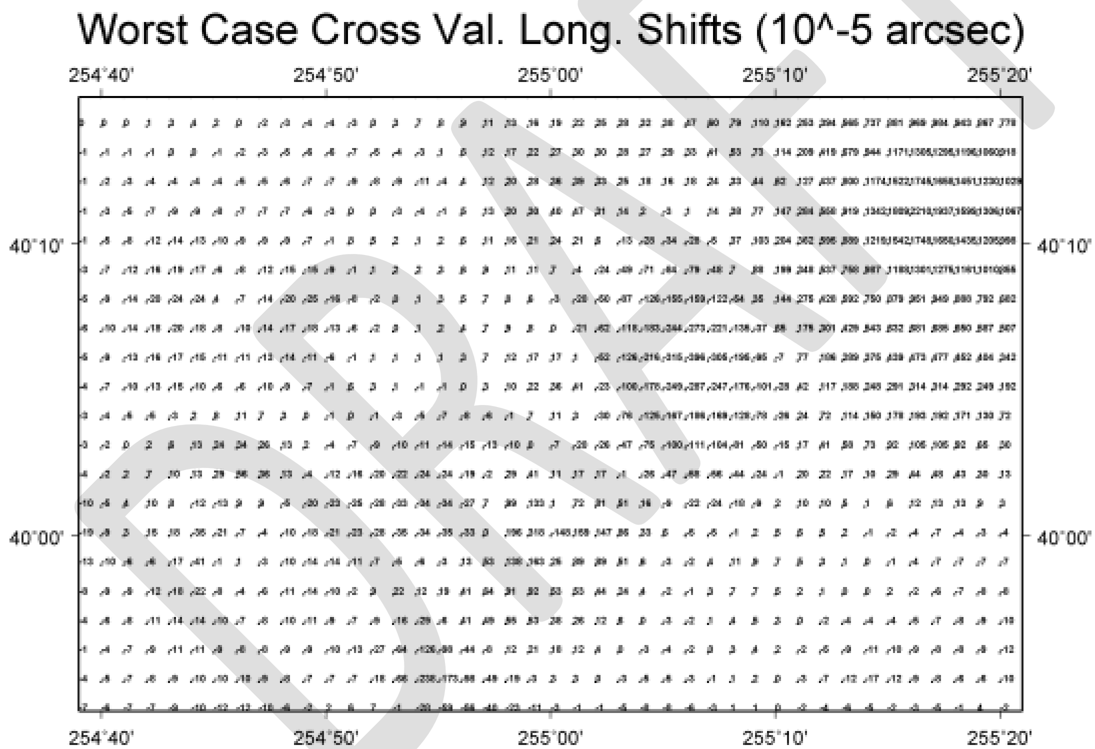


Figure 6.9. Gridded Worst Case Cross-Validation Error of Longitude Differences.

The points KK2064 and LL1240 have isolated abnormal shifts. So, their gridded errors spread out over some distance. The southern point, KK2067, is the worst case in a cluster. But the gridded error quickly decreases as one approaches the normal neighbors. The northeast point, LL1465 is in an isolated cluster. Its worst case cross-validation error passes to the gridding algorithm. And, because the cluster was isolated, the error estimate spreads over a larger distance in the quality grid.

Therefore, we see that the user is warned about the presence of abnormal coordinate shifts in the vicinity of a geospatial project. Large values in the quality grid are created by coordinate shifts that don't agree with neighboring values. And, those large values are reported whether they are isolated, or present in a cluster of normal coordinate shifts.

These quality indicator values indicate potential *systematic* error in the reported transformation. The error is not due to uncertainty in a nearby coordinate shift. The coordinate shifts used to create the GEOCON transformations are, by definition, error-free. Rather, the large quality indicator values indicate uncertainty in how a local project connected into the existing control, and what procedures were followed by the practitioner regarding misfits. The quality values should be considered systematic, and absolute values of the quality numbers should be used to increase the base network accuracy of the pre-transformed coordinates.

As a final part of this example, consider the notification messages. As discussed in the Volume I (Operating Instructions), notification messages may be generated when converting near abnormal coordinate shifts present in a cluster. The pair of abnormal points (KK2067 and LL1465) seen in Figure 6.6 are stored in an information file. Notification messages are issued when an input point has a quality indicator of 5 cm or more and is within about 5 km of an abnormal point in an information file. The notification messages are purely informational, and help indicate the source of a large quality value when a nearby cluster would create some ambiguity in diagnosis.

7. General Quality of the Coordinate Transformations by Region

The quality grids, obtained from 69-fold cross-validation, are highly variable. Even so, it is worthwhile to get a general view of how well the transformation grid is able to predict at withheld points.

The two-tailed percentiles of the distributions of the cross-validation for the conterminous U.S. are collected in Table 7.1. Approximately 68490 points were validated.

Table 7.1 – Percentiles of Cross-Validation Error, CONUS

Percentile	Latitude (0.00001 arc sec)	Longitude (0.00001 arc sec)	Ellipsoid Height (cm)
50%	3.1	3.8	0.2
68%	7.2	9.0	0.5
90%	31.2	40.9	1.9
95%	62.5	82.0	3.5
99%	324.0	405.6	8.9
99.9%	895.7	1003.6	23.6

It is seen that the 95% limits are remarkably good. We have 95% bounds of +/-1.9 cm in latitude, +/-2.0 cm in longitude, and +/-3.5 cm in ellipsoid height. Note that the distribution is not Gaussian. It is very peaked (leptokurtic), with long tails. The 68% bounds are almost 10 times smaller than the 95% bounds. In general, the quality of the coordinate transformation is remarkably good. In fact, at the 90% level it is comparable to the network accuracy of

NAD 83(NSRS2007). Of course, as discussed earlier, the cross-validation error should be treated as *systematic*. Therefore, the absolute value of the quality numbers should be used to increase the base network accuracy of the pre-transformed coordinates.

The two-tailed percentiles of the distributions of the cross-validation for Alaska are collected in Table 7.2. Approximately 770 points were validated.

Table 7.2 – Percentiles of Cross-Validation Error, Alaska

Percentile	**Latitude (0.00001 arc sec)**	**Longitude (0.00001 arc sec)**	**Ellipsoid Height (cm)**
50%	28.5	61.3	1.4
68%	67.8	162.7	3.9
90%	246.7	534.4	13.7
95%	323.7	735.3	23.3
99%	1091.3	1338.0	95.6
99.9%	1739.5	2255.1	8602.7

It is seen that the 95% limits are much poorer than for the conterminous U. S. We now have 95% bounds of +/-10.0 cm in latitude, +/-10.8 cm in longitude, and +/-23.3 cm in height. Even so, these qualities are sufficient to transform many types of geospatial data. Note that because of the small sample size (770), when the limits are established at the 99.9% boundary, height outliers are seen to appear.

The two-tailed percentiles of the distributions of the cross-validation for Puerto Rico/Virgin Islands are collected in Table 7.3. Approximately 145 points were validated.

Table 7.3 – Percentiles of Cross-Validation Error, PR/VI

Percentile	**Latitude (0.00001 arc sec)**	**Longitude (0.00001 arc sec)**	**Ellipsoid Height (cm)**
50%	5.3	7.9	0.4
68%	8.7	15.6	0.7
90%	37.1	82.3	2.3
95%	64.3	169.0	3.1
99%	112.0	400.6	5.2
99.9%	120.3	434.7	9.9

Here the 95% limits fall between those of the conterminous U.S. and Alaska. The 95% bounds are +/-2.0 cm in latitude, +/- 5.2cm in longitude, and 3.1cm in height. Note that the relatively small values at the 99% and 99.5% limits can not be given much interpretation, since the sample size is so small (145).

Note that the limits reported in Tables 7.1, 7.2, and 7.3 are general statistics. The cross-validation error is highly variable, and geographically dependent. For this reason, one should refer to the actual *94* transformation quality records generated by GEOCON for your specific transformations.

8. Images of the Transformation and Quality Grids

At this point it is useful to provide some images of the coordinate transformations from the NAD 83("HARN") to the NAD 83(NSRS2007), and the associated transformation quality grids. Only images for the conterminous U. S. are provided herein. However, many more images are available in the GEOCON Technical Report[8]. Figure 9.1 displays horizontal coordinate differences.

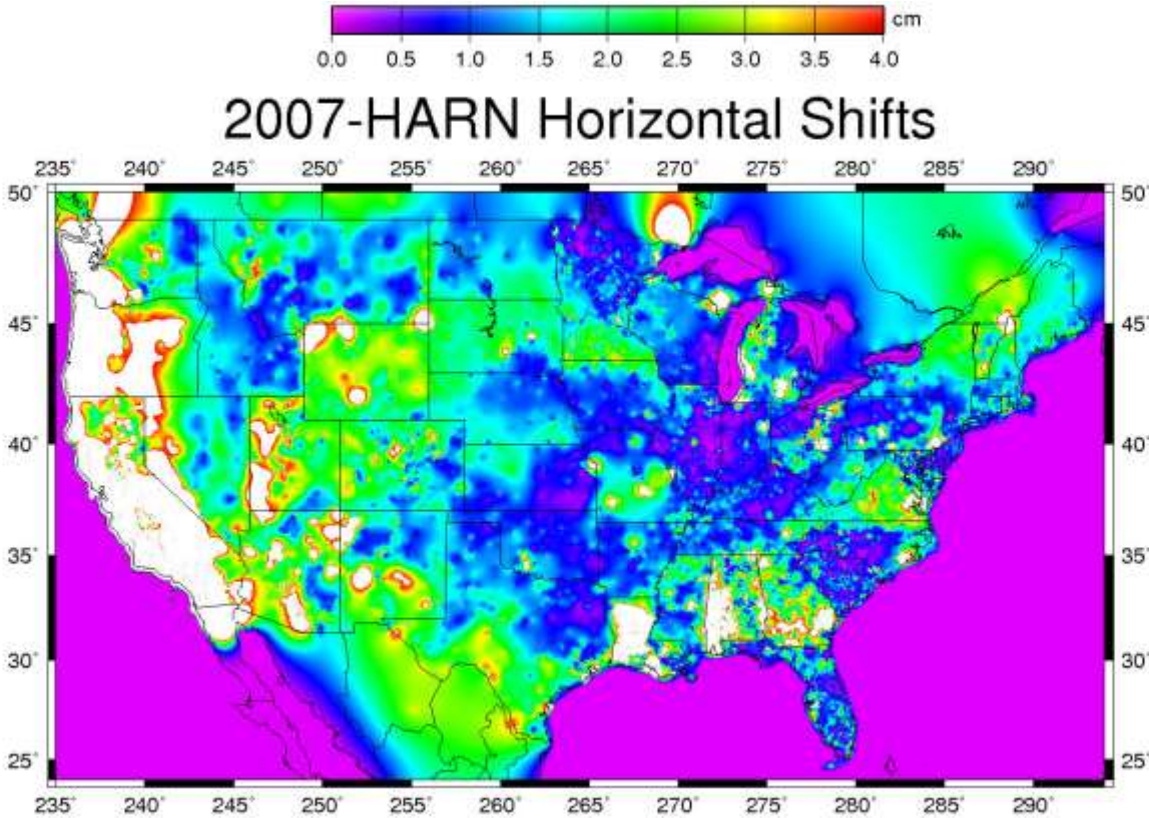


Figure 9.1. Horizontal Coordinate Differences.

The white areas in Figure 9.1 are where the horizontal shift exceeds the color scale of 4 cm. The most obvious shifts are along the West Coast of the U.S. This reflects the crustal motion of the Pacific plate between the years of 1998 and 2007 (the epochs of the California, Oregon and Washington FBN's and NSRS2007). Values in Canada and Mexico are to be disregarded. The coordinate shifts in the oceans and Great Lakes were set to near-zero to control the edge effects during the gridding process.

Also notable in Figure 9.1 are large shifts in Louisiana and portions of Alabama and Georgia. It is also seen that the color transitions sometimes conform to state boundaries. This is because the HARN adjustments were performed on groupings of one or more states (Milbert and Milbert, 1994).

[8] Note that the GEOCON Technical Report was written in conjunction with the creation of version 1.0 of GEOCON. Information contained therein may be outdated with respect to versions 1.1 or later of GEOCON.

And, it must be pointed out that the horizontal shifts in most of the country exceed the typical horizontal network accuracy of 1 cm (Milbert 2008). This demonstrates that the NSRS2007 National Readjustment was necessary to obtain those excellent network accuracies.

Next, Figure 9.2 shows the ellipsoidal height coordinate differences. White areas are where the vertical shift is greater than the color scale, and black areas are where the shift is smaller than the color scale. Of note are vertical shifts in portions of California, southern Minnesota, and Alabama.

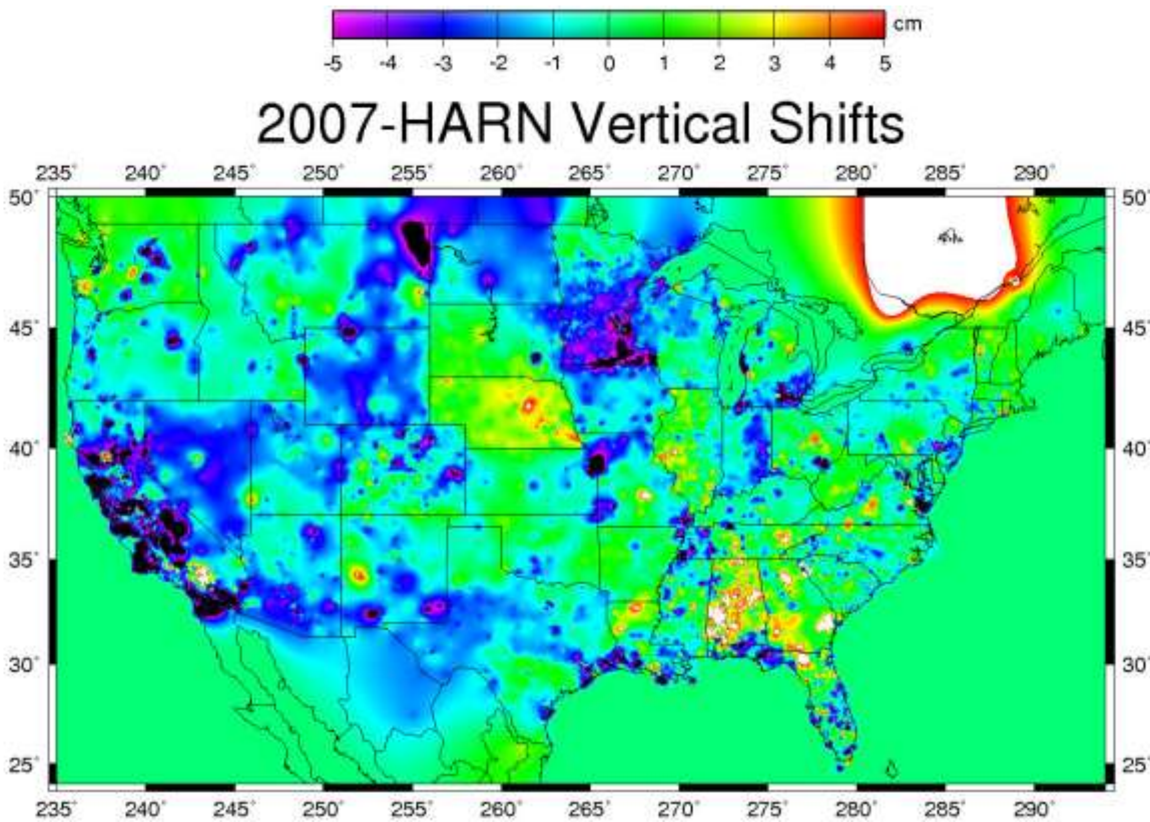


Figure 9.2. Ellipsoidal Height Coordinate Differences.

Figures 9.3, 9.4, and 9.5 plot the worst case cross-validation errors in latitude, longitude, and ellipsoidal height. These portray the transformation quality grids.

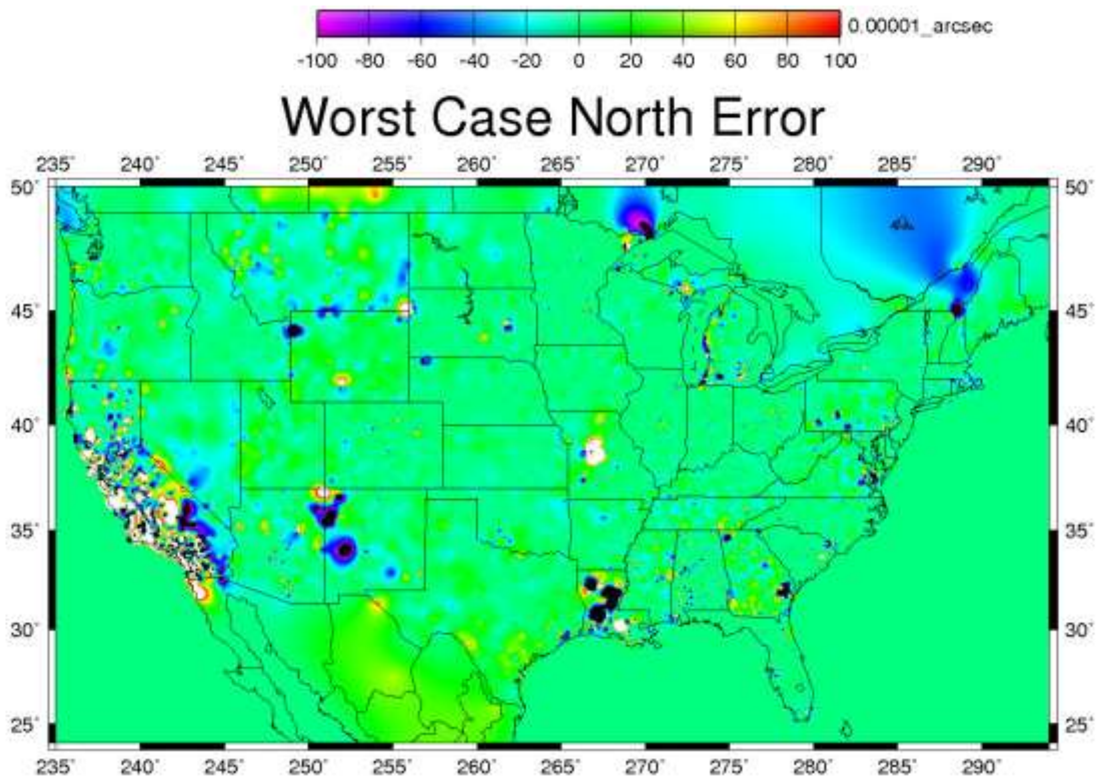


Figure 9.3. Worst Case Cross Validation Error, Latitude.

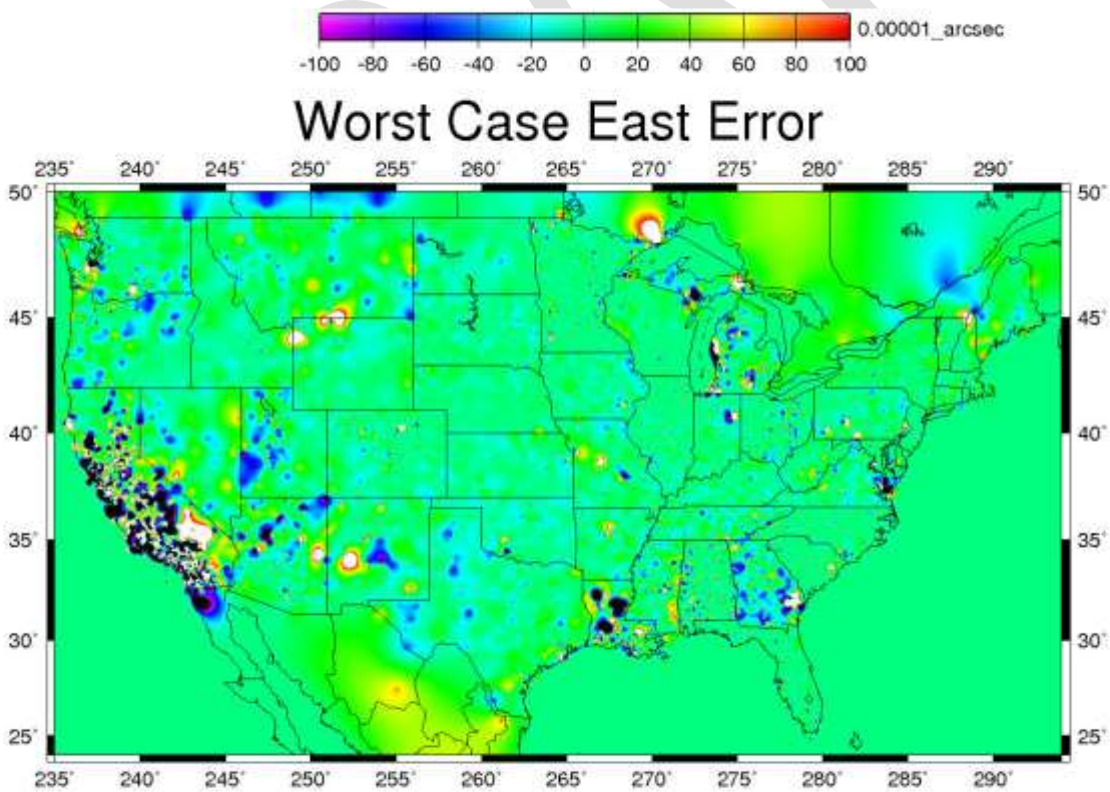


Figure 9.4. Worst Case Cross-Validation Error, Longitude.

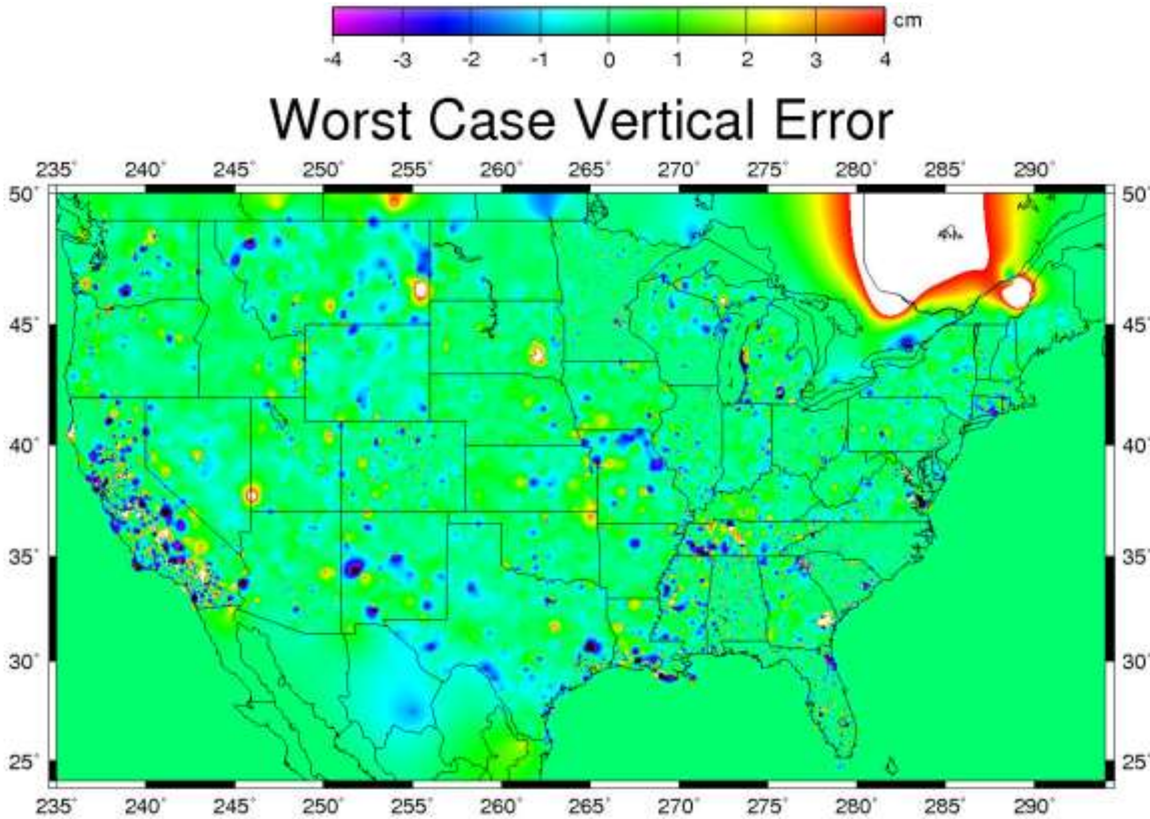


Figure 9.5. Worst Case Cross-Validation Error, Ellipsoidal Height.

The worst case error grids ("quality indicator" grids) should be inspected in conjunction with the percentiles of Table 7.1. It is seen that the coordinate shifts can be predicted quite well. The abnormal cases are quite sporadic. California and Louisiana have the most troublesome horizontal coordinate shifts. However, the vertical shifts in Louisiana are seen to be modeled somewhat better in GEOCON.

9. Case Study 1

In order to more fully understand how GEOCON transformations work, we consider a few case studies.

For the first case study, consider a GPS relative carrier phase survey in Arizona: Project GPS2828. It was observed in February 2006, and was processed in December 2010. The survey extends about 1 degree in latitude and 1.7 degrees in longitude. This survey includes 45 points, including 2 CORS. Eight passive marks were existing control points.

This project provides a means of testing the predictive capability of the GEOCON coordinate transformation. While the raw data existed in 2006, it was not included in the NSRS2007 National Readjustment. The GPS vectors were not generated until the end of 2010. The test will be to see how well NAD 83("HARN") coordinates can be transformed from starting NAD 83(NSRS2007) coordinates.

First, a constrained adjustment by means of program ADJUST (Milbert and Kass, 1987) was computed for the this project, using NAD 83(NSRS2007) coordinates on the fixed control. Eight passive control points were held fixed to the NGS database NAD 83(NSRS2007) values. The resulting set of 45 coordinates in NAD 83(NSRS2007) is denoted **bbook2007.txt**.

Then, the *80* and *86* NAD 83(NSRS2007) coordinate records were extracted from bbook2007.txt, and transformed from NAD 83(NSRS2007) into NAD 83("HARN") by program GEOCON. These transformed coordinates are designated **8086-harn.txt**. No points were clipped, and no notifications were issued. The quality values were all sub-centimeter, and were typically only a few millimeters.

Then, a "truth" coordinate set was generated by a separate constrained adjustment, only this time using the NAD 83("HARN") coordinates for the fixed control. The same set of 8 control points were held fixed to their NAD 83("HARN") values. This new set of NAD 83("HARN") coordinates were named **bbookharn.txt**. Figure 10.1 illustrates the flow of this data through the various programs.

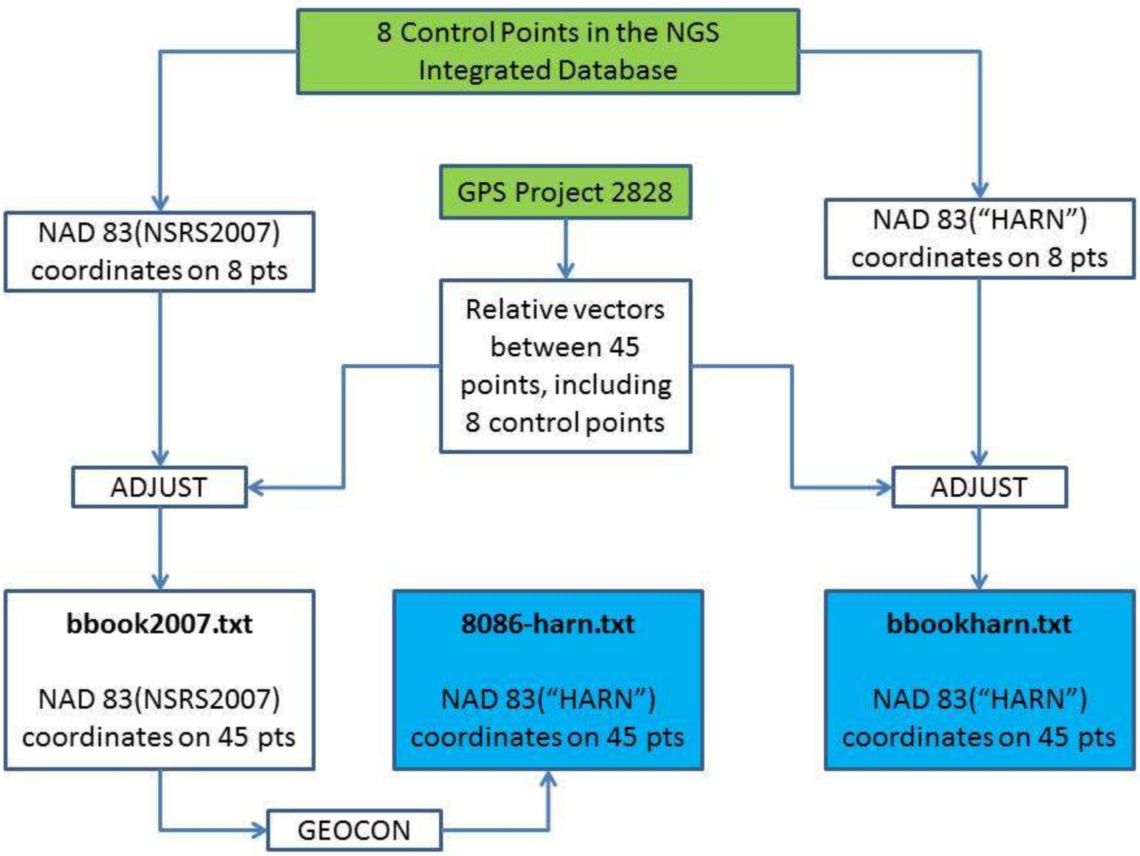


Figure 9.1. Case Study 1: Arriving at *transformed* (**8086-harn.txt**) and *adjusted* (**bbookharn.txt**) NAD 83("HARN") coordinates.

Finally, a simple program, **harnstat**, was written to compare the NAD 83("HARN") coordinates between the transformed set (**8086-harn.txt**) and the control set obtained by the NAD 83("HARN") constrained adjustment (**bbookharn.txt**). The output of **harnstat** is presented in Appendix A.2. The sense of the signs is: transformed minus adjusted. Longitudes are taken as positive East. All units are millimeters. The results are summarized in Table 9.1.

Table 9.1 – Summary Statistics for the Difference between Adjusted and Transformed NAD 83("HARN") coordinates based on project GPS2828

Statistic	Latitude (mm)	Longitude (mm)	Ellipsoid Height (mm)
Average	-0.3	-0.6	1.1
Standard Deviation	1.5	4.1	2.4
RMS	1.5	4.2	2.6

It is seen that GEOCON did a very good job of transforming the NAD 83(NSRS2007) coordinates into NAD 83("HARN") coordinates, when compared directly to an adjustment done in NAD 83("HARN") coordinates.

Of course, in this first example, the GPS survey happens to tie into points that behave very much like their neighbors. None of the 8 fixed points can be considered as having abnormal coordinate shifts between NAD 83("HARN") and NAD 83(NSRS2007).

10. Case Study 2: Abnormal Points

The second case study will consist of 3 parts. However, all 3 parts will use an identical set of GPS vectors. A suitable real-world example could not be found within the time constraints of putting together this documentation, so we consider a *synthetic* GPS project in Northeast Colorado shown in Figure 10.1.

10.1 Case Study 2, Part 1: Abnormal point LL1240 exists and is used as control

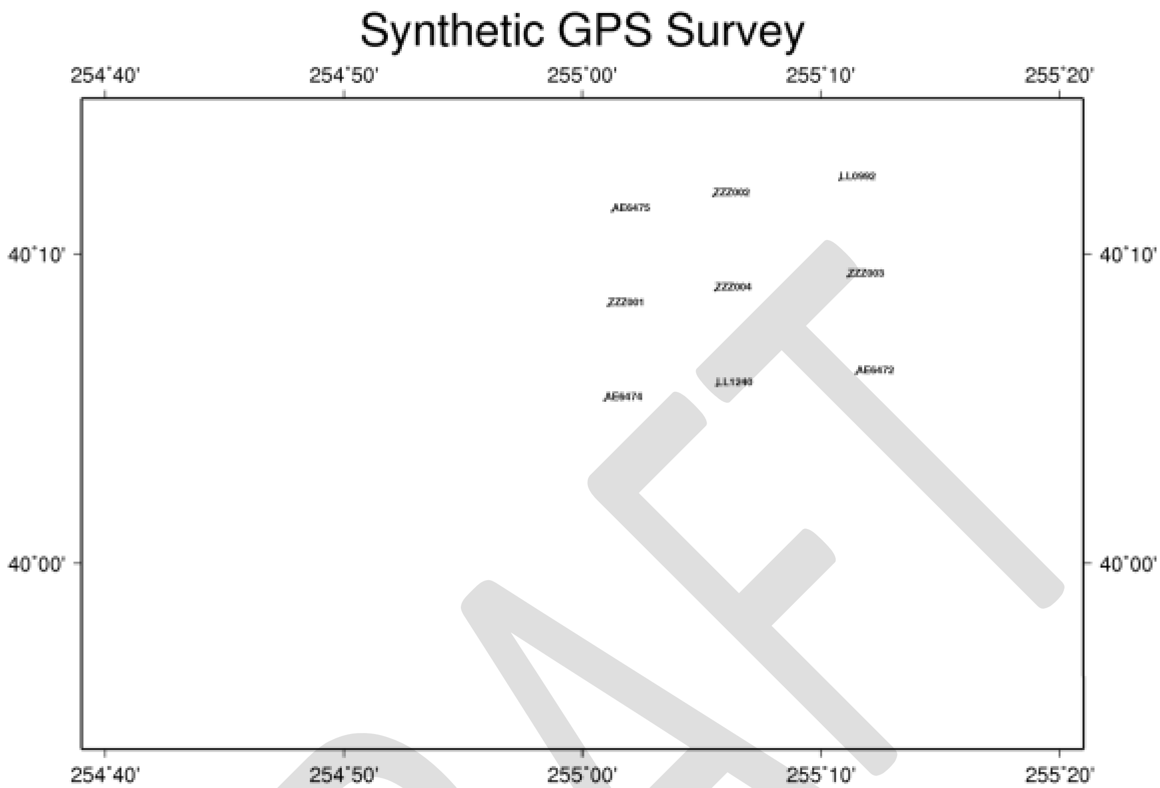


Figure 10.1. A Simulated GPS Survey.

This example represents a densification survey with 4 new points labeled with the prefix “ZZZ”. The remaining 5 points (LL1240 AE6475, LL0992, AE6474 and AE6472) are a subset of the points from the example found in Section 6. The objective is to get a set of NAD 83(“HARN”) coordinates for the new points from NAD 83(NSRS2007) coordinate values using GEOCON and compare those against a set of NAD 83(“HARN”) coordinates determined by processing the GPS data directly to the control points in NAD 83(“HARN”). Recall that the coordinate shift difference at LL1240 was abnormal (about 12 cm in longitude).

We make the important presumption that the new points’ survey connections to the established control are excellent. The synthetic GPS data consists of 12 vectors, each in a separate session, with no correlations between components. Each vector connects northward or eastward to an adjacent point. This creates quadrilaterals of 2 vectors in each of the 3 rows and 3 columns. The synthetic vector components were created by differencing NAD 83(NSRS2007) coordinates and then adding noise to each vector. Gaussian random noise of 0.5 cm standard deviation was computed by a Box-Mueller method (Forsythe et al., 1977, pg. 247), and added to each synthetic vector component.

The first part of this case study begins with a constrained adjustment of our synthetic GPS survey to the 5 control points (AE6474, LL1240, AE6472, AE6743, and LL0992) using their

NAD 83(NSRS2007) coordinates. The resulting set of 9 coordinate sets in NAD 83(NSRS2007) is denoted **bbook2007.txt**.

As in the first case study, the *80* and *86* NAD 83(NSRS2007) coordinate records were extracted from **bbook2007.txt**, and transformed from NAD 83(NSRS2007) into NAD 83("HARN") by program GEOCON. These transformed coordinates are designated **8086-harn.txt**. No points were clipped, and no notifications were issued. But, the quality values ranged up to nearly 9 cm. This is due to the influence of the longitude shift at LL1240.

The control coordinate set is generated by another constrained adjustment computed for the HARN. The same set of 5 control points were held fixed to the database HARN values. This control set in the HARN is named **bbookharn.txt**.

The above dataflow is illustrated in Figure 10.2.

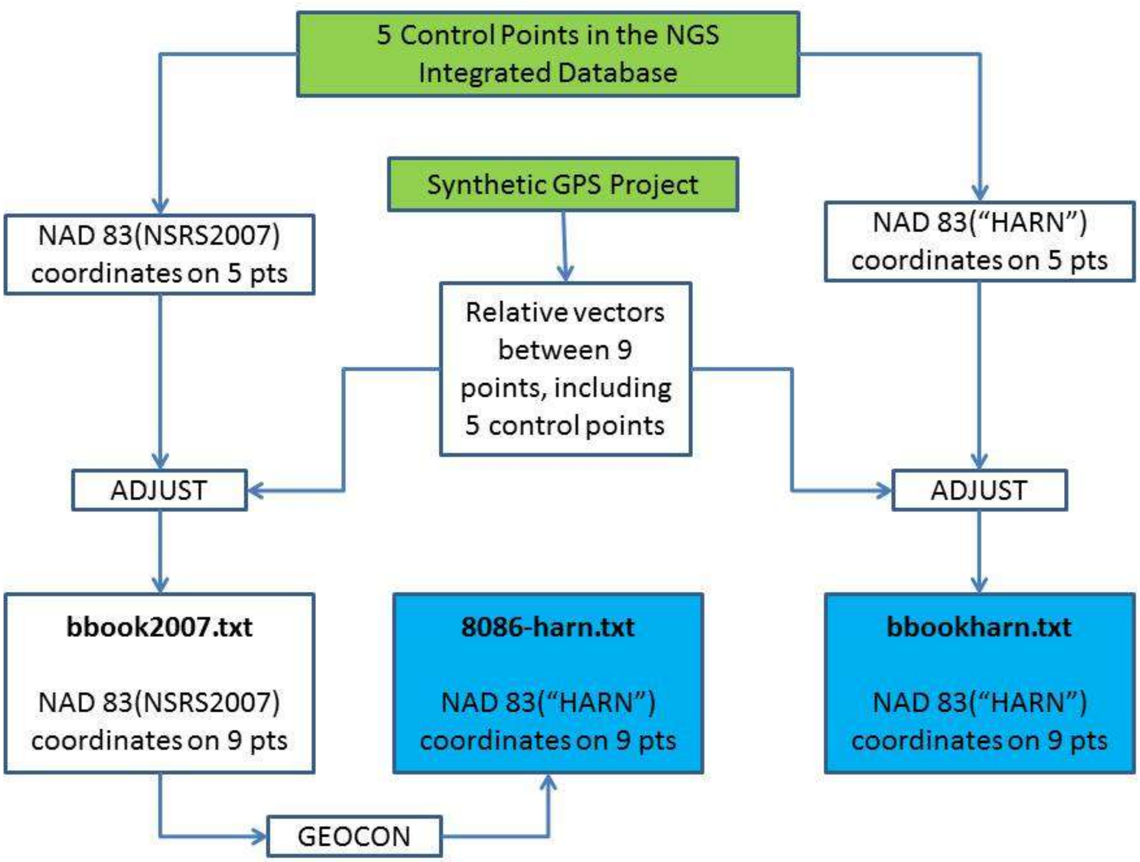


Figure 10.2. Case Study 2, Part 1: Arriving at *transformed* (**8086-harn.txt**) and *adjusted* (**bbookharn.txt**) NAD 83("HARN") coordinates.

As with the first case study, the transformed coordinates are compared against the adjusted coordinates. Results in millimeters are displayed in Tables 10.1 and 10.2

Table 10.1 – Point-by-point Statistics for the Difference between Adjusted and Transformed NAD 83(“HARN”) coordinates based on synthetic project (millimeters)							
PID	SSN	Test Comparison			Transformation quality		
		Lat	Lon	Ell Ht	Lat	Lon	Ell Ht
AE6474	0001	0.0	1.9	0.0	4.6	9.5	-9.9
LL1240	0002	0.6	-16.7	2.0	3.8	-89.7	12.8
AE6472	0003	0.3	3.1	-1.0	3.1	32.2	-10.3
ZZZ001	0004	0.3	2.8	0.0	2.9	-4.4	-3.5
ZZZ004	0005	0.0	5.3	-3.0	3.7	-22.8	1.1
ZZZ003	0006	1.9	-2.8	-2.0	11.2	89.9	-24.7
AE6475	0007	0.0	1.9	0.0	0.4	11.1	1.3
ZZZ002	0008	0.3	0.0	-5.0	2.4	3.4	-0.6
LL0992	0009	0.3	0.9	-1.0	4.6	23.0	-10.7

Table 10.2 – Summary Statistics for the Difference between Adjusted and Transformed NAD 83(“HARN”) coordinates based on synthetic project			
Statistic	Latitude (mm)	Longitude (mm)	Ellipsoid Height (mm)
Average	0.4	-0.4	-1.1
Standard Deviation	0.5	6.1	1.9
RMS	0.7	6.1	2.2

GEOCON has done a surprisingly good job in transforming the coordinates from NAD 83(NSRS2007) into NAD 83(“HARN”) despite the abnormal shift at LL1240. Though the -16.7 mm longitude difference between the two coordinate sets at LL1240 shows GEOCON has some difficulty in exactly modeling the full amount of the shift at that point. The reason for these excellent results is that the synthetic survey tied into all the surrounding control, even “abnormal” point LL1240. This is exactly the scenario that is modeled in GEOCON, since LL1240 was passed through the median filter (due to having no neighbors near enough to filter it out) and became part of the transformation grid.

10.2 Case Study 2, Part 2: Abnormal point LL1240 is *not* used as control and a *new* point is set near its previous location

In this second part, we keep the same synthetic GPS survey. But suppose that the survey was unable to connect into LL1240. Perhaps the point couldn’t be recovered. Perhaps it was destroyed when the synthetic survey was performed. In any case, at that location a new point is established, named ZZZ005.

The same procedures are followed as in part 1, only now an adjustment is performed with *four* fixed NAD 83(NSRS2007) control points and *five* new points. The 9 coordinate records are transformed from NAD 83(NSRS2007) to NAD 83(“HARN”) with GEOCON. To compare, the same 4 fixed point adjustment is done in NAD 83(“HARN”). This is illustrated in Figure 10.3.

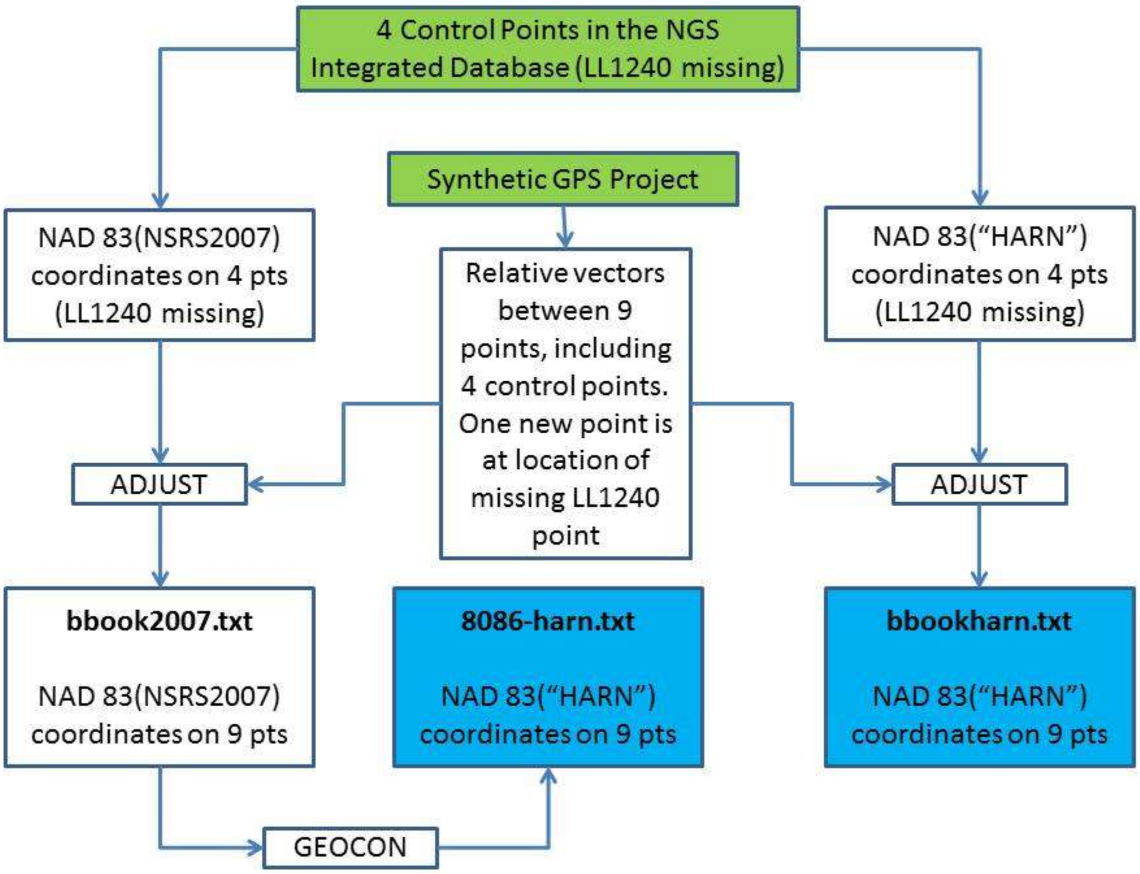


Figure 10.3. Case Study 2, Part 2: Arriving at *transformed* (**8086-harn.txt**) and *adjusted* (**bbookharn.txt**) NAD 83("HARN") coordinates.

The transformed coordinates are compared to the adjusted coordinates and given in millimeters in Tables 10.3 and 10.4.

Table 10.3 – Point-by-point Statistics for the Difference between Adjusted and Transformed NAD 83("HARN") coordinates based on synthetic project (millimeters) when LL1240 is missing and ZZZ005 is set near its old location

PID	SSN	Test Comparison			Transformation quality		
		Lat	Lon	Ell Ht	Lat	Lon	Ell Ht
AE6474	0001	0.0	1.9	0.0	4.6	9.5	-9.9
ZZZ005	0002	-3.4	119.2	-12.0	3.8	-89.7	12.8
AE6472	0003	0.3	3.1	-1.0	3.1	32.2	-10.3
ZZZ001	0004	-0.3	17.9	-2.0	2.9	-4.4	-3.5
ZZZ004	0005	-1.2	50.7	-8.0	3.7	-22.8	1.1
ZZZ003	0006	1.5	12.4	-3.0	11.2	89.9	-24.7
AE6475	0007	0.0	1.9	0.0	0.4	11.1	1.3
ZZZ002	0008	0.0	15.1	-7.0	2.4	3.4	-0.6
LL0992	0009	0.3	0.9	-1.0	4.6	23.0	-10.7

Table 10.4 – Summary Statistics for the Difference between Adjusted and Transformed NAD 83("HARN") coordinates based on synthetic project when LL1240 is missing and ZZZ005 is set near its old location			
Statistic	**Latitude (mm)**	**Longitude (mm)**	**Ellipsoid Height (mm)**
Average	-0.3	24.8	-3.8
Standard Deviation	1.3	36.5	4.0
RMS	1.3	44.1	4.0

GEOCON applied a very large (119.2 mm) longitude shift where ZZZ005 is located. And it also applied about half that amount at ZZZ004, as well as shifts of 12-18 mm at three other points (see highlights in Table 10.3). These are all erroneous shifts, as evidenced by the correct shifts shown in Table 10.2. This is because in this second part, the synthetic GPS survey was connected *solely* to points that had coordinate shifts common to one another *without* any abnormalities. Yet, the transformation grid in GEOCON *does* contain the longitude abnormality at LL1240.

Note that the transformation quality values are identical in Tables 10.2 and 10.4. The user in part 2 would not necessarily know that the shifts at ZZZ005 and ZZZ004 are erroneous based on their transformed quantities, but the large quality indicators would be evidence that some abnormality is nearby. If that abnormal point had been entirely dropped by the median filter prior to the gridding process (*not* the case for LL1240), then an additional "notification" would be issued to the user working near that dropped point.

10.3 Case Study 2, Part 3: Abnormal point LL1240 is the *only* control used and new points are set near all the other control points

In the third part of the case study, we keep the same synthetic GPS survey. But, suppose that the survey was connected to only one point, LL1240. In this case we have new points ZZZ005, ZZZ006, ZZZ007, and ZZZ008 replacing the old control at the same locations. This is a total of 8 new points, and one old point.

The same adjustment and transformation procedures are followed as before, however with just one fixed point, see Figure 10.4.

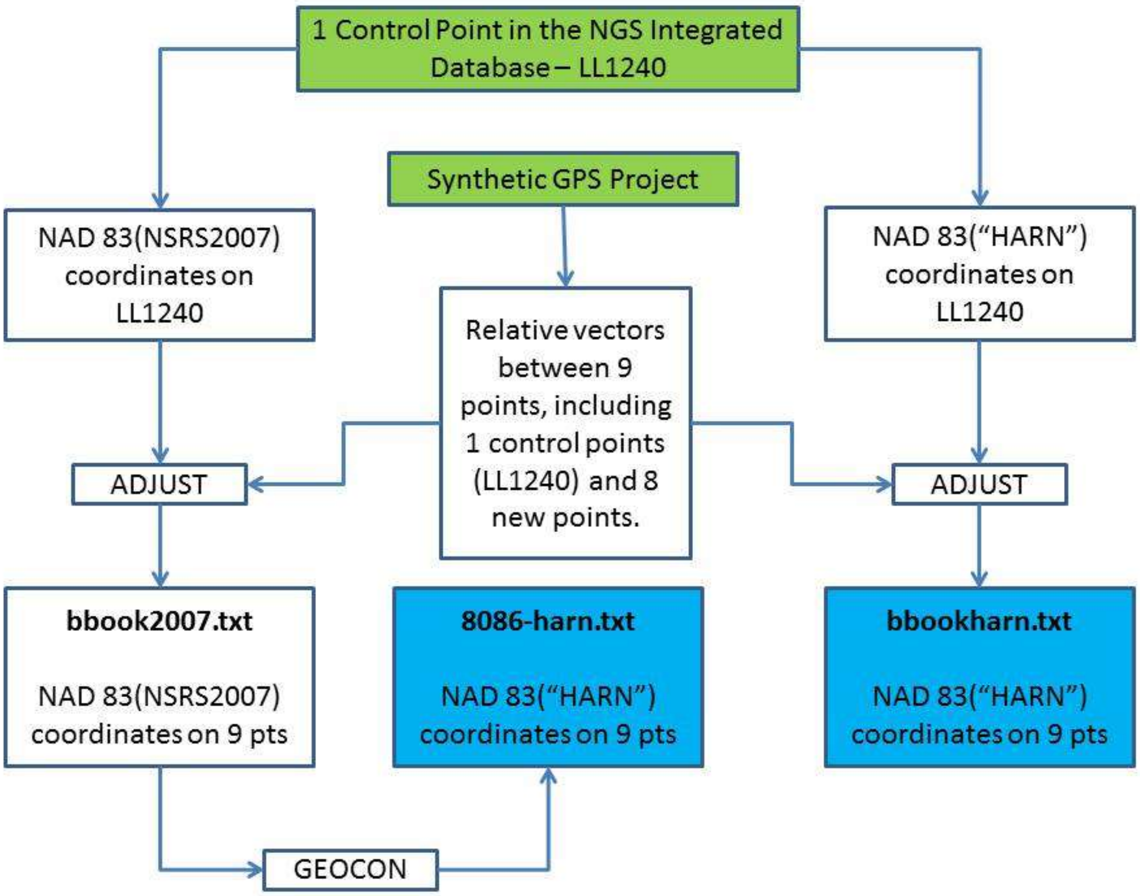


Figure 10.4. Case Study 2, Part 3: Arriving at *transformed* (**8086-harn.txt**) and *adjusted* (**bbookharn.txt**) NAD 83(“HARN”) coordinates.

The transformed coordinates are compared to the adjusted coordinates and given in millimeters in Tables 10.5 and 10.6.

Table 10.5 – Point-by-point Statistics for the Difference between Adjusted and Transformed NAD 83(“HARN”) coordinates based on synthetic project (millimeters) when only LL1240 is used as control

PID	SSN	Test Comparison			Transformation quality		
		Lat	Lon	Ell Ht	Lat	Lon	Ell Ht
ZZZ005	0001	4.6	-132.8	7.0	4.6	9.5	-9.9
LL1240	0002	0.6	-16.7	2.0	3.8	-89.7	12.8
ZZZ006	0003	2.8	-133.1	26.0	3.1	32.2	-10.3
ZZZ001	0004	4.6	-119.2	0.0	2.9	-4.4	-3.5
ZZZ004	0005	3.1	-86.2	0.0	3.7	-22.8	1.1
ZZZ003	0006	5.6	-124.5	8.0	11.2	89.9	-24.7
ZZZ007	0007	5.3	-137.4	-8.0	0.4	11.1	1.3
ZZZ002	0008	4.9	-122.9	-6.0	2.4	3.4	-0.6
ZZZ008	0009	5.6	-136.5	2.0	4.6	23.0	-10.7

Table 10.6 – Summary Statistics for the Difference between Adjusted and Transformed NAD 83(“HARN”) coordinates based on synthetic project when only LL1240 is used as control			
Statistic	**Latitude (mm)**	**Longitude (mm)**	**Ellipsoid Height (mm)**
Average	4.1	-112.2	3.4
Standard Deviation	1.6	36.8	9.4
RMS	4.4	118.0	10.0

This third part of this case study created an NAD 83(“HARN”) coordinate set that was completely anchored to LL1240. It was *only* at LL1240 that GEOCON was able to issue a coordinate shift consistent with that particular adjustment (see highlights in Table 10.5).

10.4 Case Study 2, Summary

The longitude transformation quality values in this second case study have an estimated error of -9 cm at LL1240, and -2.3 cm at ZZZ004. These errors are much too large for *part one* of this case study. However, that part of the study had ideal connections to both normal and abnormal network control points. These same quality values are a little small, but about right for part two. In part two, the survey was only connected to control points with normal longitude shifts. But in part 3 these same quality values fail to show the reverse distribution of error which was generated (seen in Table 10.5). Of course, part three is a pathological situation; where the survey is connected solely to an isolated, abnormal control point, and all the existing control in the area was ignored.

As described in Section 6, the cross-validation errors estimate how well one can predict a value at a withheld point. Hence, they can quantify abnormality of a coordinate difference. <u>This quality model is most appropriate when one only connects to normal points.</u> The quality values overestimate when one connects into both normal and abnormal points. But, gridding the worst-case cross-validation errors as “quality indicators” was deliberately selected to provide conservative estimates of error and provide maximal warning to the user. In the end, the quality indicator values do not reflect survey accuracy. Rather, <u>the quality indicators reflect our lack of knowledge about how the input coordinates are connected to the national network.</u>

These case studies provide a deeper explanation of why the National Geodetic Survey considers actual re-computation of geospatial data, and not coordinate transformations, as “best practice”. The coordinate transformation is, at its heart, only a model of actual geospatial measurement and processing.

In closing this section, it should be noted that the results would have been the same if the densification consisted of a grid of 400 new, interconnected points instead of 4. And, photogrammetric mosaics, or other interconnected geospatial positioning data, would behave similarly to synthetic GPS vectors.

11. Case Study 3: Clusters

The third case study illustrates behavior when control points are clustered. This study also consists of 3 parts. The general approach is similar to the second case study. The study involves a synthetic GPS project somewhat further to the northeast than seen in the second case study. This example also presents a densification survey with 3 new points labeled with “ZZZ”. The arrangement of points is depicted in Figure 11.1.

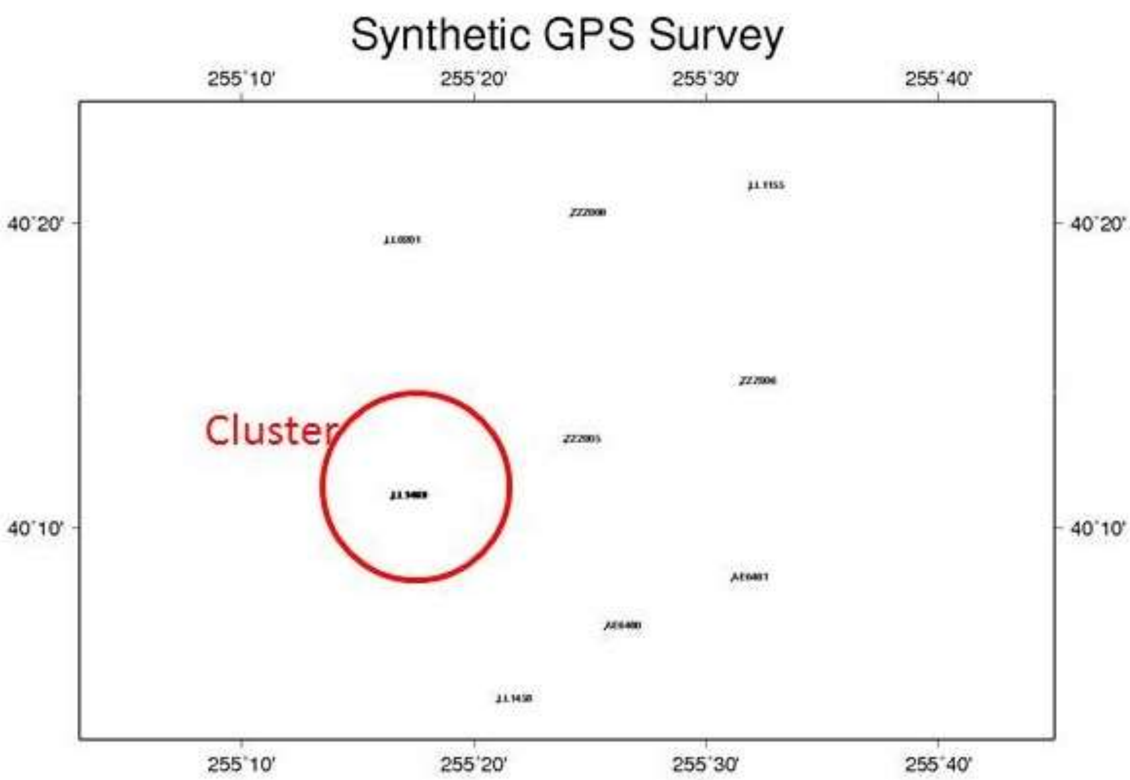


Figure 11.1. Another Simulated GPS Survey.

The West-central location in the array is actually a cluster of 7 points. For the purposes of this case study, the cluster is first thinned down to 3 points: LL1439, LL1465, and LL1477. LL1439 is a point that generally agrees with its neighbors in the network. LL1465 and LL1477, however, have abnormal coordinate shifts. The first is largely anomalous in latitude and the second is anomalous in height coordinate shift.

The synthetic GPS data consists of 12 vectors with the same general arrangement as in the second case study. However, due to the cluster at the West-Central location, the choice of control point changes for each part of this three-part study. Therefore the synthetic GPS are regenerated anew for each part.

11.1 Case Study 3, Part 1: Survey tied to normal point LL1439

In the first part of the study, the synthetic survey ties to LL1439, a normal point. A set of synthetic data was generated using the NAD 83(NSRS2007) coordinates and adding Gaussian random noise (see Case Study 1, section 9). A constrained adjustment was performed with LL1458, AE6480, AE6481, LL1155, LL0201, and LL1439 fixed in NAD 83(NSRS2007). The resulting coordinates were transformed with GEOCON into NAD 83(“HARN”). As in the second case study, a separate adjustment of the synthetic GPS data was computed in NAD 83(“HARN”). This is similar to figures 10.2, 10.3 and 10.4, and as such further figures of that type are not included herein. The transformed coordinates are compared to the adjusted coordinates and given in millimeters in Tables 11.1 and 11.2.

Table 11.1 – Point-by-point Statistics for the Difference between Adjusted and Transformed NAD 83(“HARN”) coordinates based on synthetic project (millimeters) when using 6 control points, including normal point LL1439

PID	SSN	Test Comparison			Transformation quality		
		Lat	Lon	Ell Ht	Lat	Lon	Ell Ht
LL1458	0001	0.3	0.3	0.0	5.3	7.2	-10.7
AE6480	0002	0.0	-0.3	0.0	1.8	5.6	-2.8
AE6481	0003	0.0	0.0	0.0	1.4	0.9	-6.2
LL1439	0004	3.4	0.6	2.0	51.2	510.3	-116.8
ZZZ005	0005	1.9	-0.9	0.0	12.5	115.1	-27.3
ZZZ006	0006	0.9	-0.3	2.0	3.7	26.1	-8.6
LL0201	0007	0.3	0.0	0.0	4.5	4.7	2.6
ZZZ008	0008	7.4	-4.6	-10.0	1.5	30.1	-3.9
LL1155	0009	0.3	-0.3	0.0	3.8	-2.8	0.5

Table 11.2 – Summary Statistics for the Difference between Adjusted and Transformed NAD 83(“HARN”) coordinates based on synthetic project when using 6 control points, including normal point LL1439

Statistic	Latitude (mm)	Longitude (mm)	Ellipsoid Height (mm)
Average	1.6	-0.6	-0.7
Standard Deviation	2.3	1.5	3.4
RMS	2.8	1.6	3.5

It is seen that the transformed set of NAD 83(“HARN”) coordinates have excellent agreement with the coordinates generated by the adjustment of the synthetic data in NAD 83(“HARN”) coordinates. However, very large transformation quality values were issued by GEOCON (see especially points LL1439 and ZZZ005 in Table 11.1). In addition, GEOCON issued a pair of notification messages:

```
Large (  41.66 cm) LON qual. value near  40.1991587306 ,
255.2740982250 might be caused by nearby pt LL1465 whose LON
shift of   55.63 cm was not part of the transformation grid
```

`Large (  -9.54 cm) EHT qual. value near  40.1991587306 , 255.2740982250 might be caused by nearby pt LL1477 whose EHT shift of  -12.56 cm was not part of the transformation grid`

Both messages were issued for station LL1439. That point is completely benign and had a good transformation. However, GEOCON knows that in the NGS database are two points (LL1465 and LL1477) both of whom happen to have two qualities which together cause a cautionary notification: (1) they are in a tight (within 1' x 1') cluster of points and (2) their NAD 83("HARN") versus NAD 83(NSRS2007) coordinates are outliers in at least one coordinate relative to the points in their cluster. As such, these points were each *dropped* in the median process prior to the creation of the transformation grids. Therefore the GEOCON transformation grids do *not* model the behavior of those 2 points.

However, since the transformation quality grid is based on the worst case behavior of the cross-validation error, the large values in the transformation *quality* are a warning that some anomalous points are nearby. The notifications are a special warning that these anomalous points have a behavior that is *not* represented in the transformation grid.

Since the survey in this first part *only* connected to control with *normal* coordinate shifts the transformation quality (Table 11.1) seem much too large. But GEOCON does not know what control is used by the user. It only knows that the user wants a transformation near a cluster containing a known "abnormal" point, and therefore will always issue a large "quality" value in this location to reflect the possibility that a user has a survey or other geospatial product which *might* have tied to that abnormal point.

11.2 Case Study 3, Part 2: Survey tied to abnormal (in latitude) point LL1465

Consider a similar situation to part 1, but now where the synthetic survey ties to an abnormal point, LL1465 in the cluster of points in the west central part of the survey.

In this second part, point, LL1465 replaces LL1439. A new set of synthetic data was generated using the NAD 83(NSRS2007) coordinates and adding Gaussian random noise. A constrained adjustment was performed with LL1458, AE6480, AE6481, LL1155, LL0201, and LL1465 fixed in NAD 83(NSRS2007). The resulting coordinates were transformed with GEOCON into NAD 83("HARN"). As in the first part, a separate adjustment of the synthetic GPS data was computed in NAD 83("HARN"). The transformed coordinates were compared to the adjusted coordinates and given in millimeters in Tables 11.3 and 11.4.

Table 11.3 – Point-by-point Statistics for the Difference between Adjusted and Transformed NAD 83("HARN") coordinates based on synthetic project (millimeters) when using 6 control points, including abnormal (in latitude) point LL1465

PID	SSN	Test Comparison			Transformation quality		
		Lat	Lon	Ell Ht	Lat	Lon	Ell Ht
LL1458	0001	0.3	0.3	0.0	5.3	7.2	-10.7
AE6480	0002	0.0	-0.3	0.0	1.8	5.6	-2.8

AE6481	0003	0.0	0.0	0.0	1.4	0.9	-6.2
LL1465	0004	55.6	728.3	-28.0	51.4	512.2	-117.2
ZZZ005	0005	17.0	217.8	-8.0	12.5	115.1	-27.3
ZZZ006	0006	5.9	72.6	-1.0	3.7	26.1	-8.6
LL0201	0007	0.3	0.0	0.0	4.5	4.7	2.6
ZZZ008	0008	12.7	68.3	-13.0	1.5	30.1	-3.9
LL1155	0009	0.3	-0.3	0.0	3.8	-2.8	0.5

Table 11.4 – Summary Statistics for the Difference between Adjusted and Transformed NAD 83("HARN") coordinates based on synthetic project when using 6 control points, including abnormal (in latitude) point LL1465

Statistic	Latitude (mm)	Longitude (mm)	Ellipsoid Height (mm)
Average	10.2	120.7	-5.6
Standard Deviation	17.1	225.2	9.1
RMS	19.9	255.6	10.6

Table 11.3 shows that the transformation qualities that were issued in part one of this case study (Table 11.1) were not, in fact, too large for the area around cluster containing LL1465. In fact, the quality values underestimate the actual error between the transformed and the adjusted coordinate sets. Recall, the same GEOCON transformation grids were used in parts one and two. In the first part, the transformation performed excellently. In the second part, the transformation did not. The difference is due to the way the local data tied into the network. NGS (and thus GEOCON) cannot know how such projects connect into the national network. But, GEOCON can warn the user that potential problems might exist.

11.3 Case Study 3, Part 3: Survey tied to abnormal (in height) point LL1477

In the third part, point, LL1477 replaces LL1439 and/or LL1465. New synthetic data was generated as before. A constrained adjustment was performed with LL1458, AE6480, AE6481, LL1155, LL0201, and LL1477 fixed in NAD 83 (NSRS2007) coordinates. The remaining procedures follow parts one and two. The transformed coordinates are compared to the adjusted and given in millimeters in Tables 11.5 and 11.6.

Table 11.5 – Point-by-point Statistics for the Difference between Adjusted and Transformed NAD 83("HARN") coordinates based on synthetic project (millimeters) when using 6 control points, including abnormal (in height) point LL1477

PID	SSN	Test Comparison			Transformation quality		
		Lat	Lon	Ell Ht	Lat	Lon	Ell Ht
LL1458	0001	0.3	0.3	0.0	5.3	7.2	-10.7
AE6480	0002	0.0	-0.3	0.0	1.8	5.6	-2.8
AE6481	0003	0.0	0.0	0.0	1.4	0.9	-6.2
LL1477	0004	-0.9	-4.3	-126.0	51.4	512.6	-117.3
ZZZ005	0005	0.3	-2.2	-38.0	12.5	115.1	-27.3
ZZZ006	0006	0.3	-0.6	-11.0	3.7	26.1	-8.6

LL0201	0007	0.3	0.0	0.0	4.5	4.7	2.6
ZZZ008	0008	7.1	-4.9	-22.0	1.5	30.1	-3.9
LL1155	0009	0.3	-0.3	0.0	3.8	-2.8	0.5

Table 11.6 – Summary Statistics for the Difference between Adjusted and Transformed NAD 83("HARN") coordinates based on synthetic project when using 6 control points, including abnormal (in height) point LL147

Statistic	Latitude (mm)	Longitude (mm)	Ellipsoid Height (mm)
Average	1.6	-0.6	-0.7
Standard Deviation	2.3	1.5	3.4
RMS	2.8	1.6	3.5

Table 11.5 illustrates what occurs when the survey ties to the point with the anomalous height shift. The transformation quality indicator is distributed very much the same as seen in part two, only in the height component. The transformation quality indicators are reflecting both anomalous points.

12. Summary User Guidance

If at all possible, consider reprocessing your geospatial data using control points in the coordinate set you wish to realize. In the case of geodetic survey data, this would entail performing a least squares adjustment on original observations but with new coordinates on constrained control. Notwithstanding the high quality of the GEOCON transformation, the National Geodetic Survey considers actual readjustment of survey measurements, and not coordinate transformations, as "best practice".

It is understood that for many cases it will not be economical, or may be impossible to work with the original geospatial measurements. Further, the network accuracy of the geospatial data set may be a much larger number than the expected quality value of the coordinate transformation. GEOCON provides an attractive solution.

The quality values reported by GEOCON in the *94* records are systematic, and their absolute values should be added to the base network accuracy of the pre-transformed coordinates. If your transformed accuracies meet your needs, then congratulations, you are done.

However, there may be some spots where the transformation does not have the desired quality. These are caused by proximity to abnormal coordinate differences. The abnormal point or points may be isolated or in clusters. If they are isolated, they will be expressed in the transformation grid. If in a cluster, they will likely *not* be expressed in the transformation grid. Either way, the abnormality (assuming it is the worst-case in a cluster) *will* be expressed in the quality grids. Short of reprocessing the raw data, one is faced with researching how the raw data was connected, directly or indirectly, to the network in order to fully understand the situation specific to your project.

In the case of isolated anomalous points, the transformation grid is modeling the general behavior of a data set connected to every point in the region *including* the anomalous point. If this is the case for the original raw data, the coordinate transformation will be better than the reported quality. On the other hand, if the raw data connected solely to the normal points, or solely to the isolated anomalous point, then the transformation should be applied manually.

In the case of an anomalous point in a cluster, the transformation grid is modeling the connection to the normal points, including the median normal point in the cluster. If this is the case for the original raw data, the coordinate transformation will be better than the reported quality. However, if the raw data connected to the anomalous point and other normal points, then one must estimate how the anomalous coordinate shift will be distributed between the anomalous point and its neighbors. And, if the raw data connected solely to the anomalous point in the cluster, then the transformation based on the anomalous point should be applied manually.

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APPENDIX A: Datasheet for M 123

```
1 National Geodetic Survey, Retrieval Date = NOVEMBER 25, 2011
TT2413 ***********************************************************************
TT2413 DESIGNATION - M 123
TT2413 PID - TT2413
TT2413 STATE/COUNTY- AK/DENALI BOROUGH
TT2413 USGS QUAD - HEALY C-4
TT2413
TT2413 *CURRENT SURVEY CONTROL
TT2413 ___________________________________________________________________
TT2413* NAD 83(2007)- 63 43 21.43573(N) 148 57 43.76796(W) ADJUSTED
TT2413* NAVD 88 - 628.189 (meters) 2060.98 (feet) ADJUSTED
TT2413 ___________________________________________________________________
TT2413 EPOCH DATE - 2007.00
TT2413 X - -2,426,212.599 (meters) COMP
TT2413 Y - -1,459,997.451 (meters) COMP
TT2413 Z - 5,696,668.363 (meters) COMP
TT2413 LAPLACE CORR- -8.38 (seconds) DEFLEC09
TT2413 ELLIP HEIGHT- 641.786 (meters) (07/17/09) ADJUSTED
TT2413 GEOID HEIGHT- 13.66 (meters) GEOID09
TT2413 DYNAMIC HT - 629.112 (meters) 2064.01 (feet) COMP
TT2413 MODELED GRAV- 982,033.7 (mgal) NAVD 88
TT2413
TT2413 HORZ ORDER - FIRST
TT2413 VERT ORDER - FIRST CLASS II
TT2413 ELLP ORDER - FOURTH CLASS I
TT2413
TT2413.The horizontal coordinates were established by GPS observations
TT2413.and adjusted by the National Geodetic Survey in July 2009.
TT2413
TT2413.The datum tag of NAD 83(2007) is equivalent to NAD 83(NSRS2007).
TT2413.The horizontal coordinates are valid at the epoch date displayed above.
TT2413.The epoch date for horizontal control is a decimal equivalence
TT2413.of Year/Month/Day.
TT2413
TT2413.The orthometric height was determined by differential leveling and
TT2413.adjusted in June 1991.
TT2413.WARNING-GPS observations at this control monument resulted in a GPS
TT2413.derived orthometric height which differed from the leveled height by
TT2413.more than one decimeter (0.1 meter).
TT2413
TT2413.The X, Y, and Z were computed from the position and the ellipsoidal ht.
TT2413
TT2413.The Laplace correction was computed from DEFLEC09 derived deflections.
TT2413
TT2413.The ellipsoidal height was determined by GPS observations
TT2413.and is referenced to NAD 83.
TT2413
TT2413.The geoid height was determined by GEOID09.
TT2413
TT2413.The dynamic height is computed by dividing the NAVD 88
TT2413.geopotential number by the normal gravity value computed on the
TT2413.Geodetic Reference System of 1980 (GRS 80) ellipsoid at 45
TT2413.degrees latitude (g = 980.6199 gals.).
TT2413
TT2413.The modeled gravity was interpolated from observed gravity values.
TT2413
TT2413; North East Units Scale Factor Converg.
TT2413;SPC AK 4 - 1,083,325.355 551,279.408 MT 0.99993219 +0 55 50.2
TT2413;UTM 06 - 7,067,593.809 403,087.880 MT 0.99971501 -1 45 34.3
TT2413
```

```
TT2413! - Elev Factor x Scale Factor = Combined Factor
TT2413!SPC AK 4 - 0.99989959 x 0.99993219 = 0.99983179
TT2413!UTM 06 - 0.99989959 x 0.99971501 = 0.99961463
TT2413
TT2413 SUPERSEDED SURVEY CONTROL
TT2413
TT2413 NAD 83(2007)- 63 43 21.43619(N) 148 57 43.77233(W) AD(2007.00) 0
TT2413 ELLIP H (02/10/07) 486.989 (m) GP(2007.00)
TT2413 NAD 83(1992)- 63 43 21.43370(N) 148 57 43.78028(W) AD( ) 1
TT2413 ELLIP H (06/20/05) 486.945 (m) GP( ) 4 1
TT2413 NAVD 88 (07/17/09) 628.19 (m) 2061.0 (f) LEVELING 3
TT2413 NAVD 88 (06/20/05) 474.1 (m) 1555. (f) GPS OBS
TT2413 NGVD 29 (??/??/92) 626.505 (m) 2055.46 (f) ADJ UNCH 1 2
TT2413
TT2413.Superseded values are not recommended for survey control.
TT2413.NGS no longer adjusts projects to the NAD 27 or NGVD 29 datums.
TT2413
TT2413_U.S. NATIONAL GRID SPATIAL ADDRESS: 6VVR0308767593(NAD 83)
TT2413_MARKER: DD = SURVEY DISK
TT2413_SETTING: 36 = SET IN A MASSIVE STRUCTURE
TT2413_SP_SET: SET IN BRIDGE
TT2413_STAMPING: M 123
TT2413_MAGNETIC: N = NO MAGNETIC MATERIAL
TT2413_STABILITY: B = PROBABLY HOLD POSITION/ELEVATION WELL
TT2413_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
TT2413+SATELLITE: SATELLITE OBSERVATIONS - May 31, 1989
TT2413
TT2413 HISTORY - Date Condition Report By
TT2413 HISTORY - 1965 MONUMENTED CGS
TT2413 HISTORY - 19890531 GOOD JOA
TT2413
TT2413 STATION DESCRIPTION
TT2413
TT2413'DESCRIBED BY COAST AND GEODETIC SURVEY 1965
TT2413'1.8 MI W FROM MCKINLEY PARK.
TT2413'1.8 MILES WEST ALONG THE MCKINLEY PARK HIGHWAY FROM THE RAILROAD
TT2413'STATION AT MCKINLEY PARK, 0.2 MILE NORTHEAST OF THE ENTRANCE TO THE MT
TT2413'MCKINLEY NATIONAL PARK HEADQUARTERS, 12 FEET SOUTHEAST OF THE CENTER
TT2413'LINE OF THE HIGHWAY, SET IN THE TOP OF THE EAST CURB OF A CONCRETE
TT2413'BRIDGE OVER ROCK CREEK, 15 FEET SOUTHWEST OF THE NORTHEAST END OF A
TT2413'CONCRETE GUARDRAIL, AND ABOUT 0.6 FOOT HIGHER THAN THE ROAD.
TT2413
TT2413 STATION RECOVERY (1989)
TT2413
TT2413'RECOVERY NOTE BY JOHN OSWALD AND ASSOCIATES, LLC 1989
TT2413'THE STATION IS LOCATED 0.2 KM (0.10 MI) NORTH EAST OF THE MCKINLEY
TT2413'PARK HEADQUARTERS, 6.3 KM (3.90 MI) WEST OF THE PARKS HIGHWAY, IN A
TT2413'BRIDGE OVER ROCK CREEK. OWNERSHIP, NATIONAL PARK SERVICE. TO REACH
TT2413'THE STATION FROM THE INTERSECTION OF THE PARKS HIGHWAY AND THE
TT2413'MCKINLEY PARK ROAD, DRIVE WEST ON THE ACCESS ROAD 6.3 KM (3.90 MI) TO
TT2413'THE ROCK CREEK BRIDGE. STATION IS ON THE LEFT. THE STATION IS A 7.6
TT2413'CM BRASS DISK SET IN THE SOUTH EAST BRIDGE ABUTMENT OF THE ROCK CREEK
TT2413'BRIDGE, LOCATED 3.6 M (11.8 FT) SOUTHEAST OF THE CENTERLINE OF THE
TT2413'ROAD, 4.5 M (14.8 FT) SOUTHWEST OF THE END OF THE ABUTMENT, 0.3 M (1.0
TT2413'FT) NORTHEAST OF A WITNESS DECAL ON THE RAIL OF THE BRIDGE. NOTE, THE
TT2413'MAGNETIC PROPERTIES OF THE STATION ARE UNKNOWN.
```

APPENDIX B: "HARN" Coordinates

Unlike NAD 83(1986), NAD 83(NSRS2007) and NAD 83(2011), there is no single HARN coordinate realization for NAD 83. The "why" of this is briefly discussed below.

The coordinate computations of the NSRS (National Spatial Reference System) underwent an explosion in the early GPS years. The name, HARN, itself, underwent evolution from High Precision Network (HPN) to High Precision Geodetic Network (HPGN) to High Accuracy Geodetic Network (HARN). Despite the name changes, these acronyms all refer to a GPS backbone campaign observed to the highest standards on a generally state-by-state basis. As the effort approached completion, GPS reduction software and models improved to the level that significantly better ellipsoid heights were obtained. This lead to an additional cycle of nationwide GPS HARN surveys, referred to as the FBN/CBN (Federal Base Network/Cooperative Base Network).

From the geodetic network standpoint, it would have been ideal to complete all the observations and re-observations, and then issue a new set of national coordinates. However the public demand for higher accuracy geodetic control could not be met if NGS waited for all the surveys to be completed. This point is so important that it bears repeating:

> **Based on customer demand, NGS chose to provide users with the most *expedient* solution rather than the most geodetically *ideal* solution.**

The complications arising from this decision are enormous and to this day have wide-ranging ramifications. Based on experiences gained from the HARN/FBN decision, it seems highly unlikely that NGS will ever again issue state-by-state solutions to any geodetic surveys that are part of a years-long nationwide effort.

Nonetheless, NGS did not have the benefit of hindsight at the beginning of this process, and so in 1990 distinct coordinate sets for least squares adjustments of one or more states began to be issued. NGS continued this process through the 15 year HPN, HPGN, HARN, FBN/CBN evolution.

The coordinates in this period are expressed as a datum tag in the form: NAD 83(nnnn), where "nnnn" is a notional date of the GPS survey observations. It is important to note that, for example, the datum tag NAD 83(1994) in Utah refers to a different realization than NAD 83(1994) in Michigan.

In addition, a majority of the states were re-observed as part of the FBN/CBN. To reduce the impact of the inevitable coordinate changes, a flexible, 5 centimeter horizontal coordinate tolerance was adopted. If newer horizontal coordinates did not change by more than 5 cm, then the old horizontal coordinates were retained. In these cases the older datum tag was retained, even though the ellipsoidal heights were always updated with the latest GPS surveys and reductions.

For example, consider point AA2203 in Alabama. After the **HARN** was completed in Alabama in **1992**, the datasheet for this point would have shown the following NAD 83(1992) values:

Latitude ,	NAD 83(1992):	N311622.40363
Longitude ,	NAD 83(1992):	W0874531.17313
Ellipsoid Height,	NAD 83(1992):	-15.717

Yet after the **FBN** was finished in **1998** the latitude and longitude were found to be within the 5 cm tolerances. But the ellipsoid height was changed, without changing the datum tag. That is, the data sheet would now show:

Latitude ,	NAD 83(1992):	N311622.40363
Longitude ,	NAD 83(1992):	W0874531.17313
Ellipsoid Height,	NAD 83(1992):	-15.808

In this case the old -15.717 value would be in the superseded section.

In cases where the horizontal coordinates did exceed the 5 cm tolerance, all horizontal and vertical coordinates were updated, and a new datum tag was issued. Note that one can not look at an older datum tag, such as NAD 83(1994) in Ohio, and immediately tell if the associated coordinates are traceable to an earlier HARN adjustment, or to the later FBN/CBN phase. If this seems confusing, it's because it is, and admittedly so. This situation of sometimes using the old datum tag and sometimes not has led to some states adopting just one "HARN" realization (albeit with two possible ellipsoid heights) and some states having very distinct differences between the HARN and the FBN realizations of NAD 83 in their state.

For the above confusion alone, we re-iterate: It seems highly unlikely that NGS will ever again issue state-by-state solutions to any geodetic surveys that are part of a years-long nationwide effort.

Version 1.0 and 1.1 of GEOCON do not distinguish between HARN, FBN or any mix of the two. GEOCON was developed with the latest coordinates available in the NGS database in both the NSRS2007 and the "HARN" coordinate sets, where here the term "HARN" means "most recent post-1986, pre-2007 published coordinate on a point". Future versions of GEOCON will distinguish between HARN and FBN in those states where the two realizations are distinct.